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DATA AND DATA MANAGEMENT

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Publisher *Kasey Thompson*
Managing Editor *Drew Brown*
Associate Editor *Chelene Fortier-Lozancich*
Publishing Coordinator *Nicole Kentta*
Phone (801) 775-5555
E-mail stsc.customerservice@hill.af.mil
CrossTalk Online www.stsc.hill.af.mil/crosstalk

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S T S C

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517 SMXS/MXDEA
6022 Fir AVE
BLDG 1238
Hill AFB, UT 84056-5820

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Data and Data Management

Data drives decisions. This statement may sound too simplistic, but the truth remains that humans need, crave, and desire data. Data is used in nearly every choice we make, from the most mundane decisions such as where to dine (location, taste, caloric content, type of food, price) to the selection of a fabric softener (aroma, effectiveness, volume, eco-friendliness, price).

Data inundation and "analysis paralysis" are real dangers due to the ease of access and abundance of information. Additionally, the mobility of personal computing devices creates a data wave, cresting at our fingertips. It can overwhelm any person, anywhere on the planet, at any time.

Data enters our lives at breakneck speeds and frequencies. Your commute to work likely involves various data deliverables: AM/FM radio broadcasts, satellite transmissions, billboard advertisements, traffic signs and signals, marquee commercials, and the odd gesture from a fellow commuter.

The real data feast begins when we arrive at work and begin interfacing with faxes, e-mails, text messages, telephone calls, status reports, market forecasts, meeting charts, figures, facts, the rumor mill, and even simple co-worker chitchat. What is a person to do with it all? Many of us will begin to filter based upon priority, but this presents a danger of filtering too much or becoming overwhelmed due to insufficient filtering. We must learn to manage and leverage data effectively to be successful in today's business environment as well as in our daily lives. The December issue of CrossTalk is here to help software professionals make sense of it all.

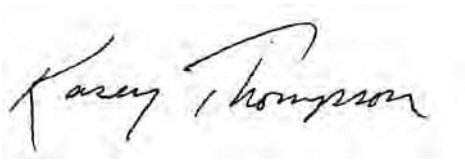
In Dr. Joseph P. Avery's article, *A Different Kind of Web-Based Knowledge Management: The DTRA Acquisition ToolBook*, he shares the Defense Threat Reduction Agency's method of intelligent storage and timely dissemination of data—to the right people at the right time via the Web.

Sandy Schwalb offers assistance if you suffer from a lack of qualified data. Her article, *The Defense Technical Information Center: Information for the Defense Community*, provides compelling reasons for utilizing this virtual treasure trove of structured, vetted, and certified information.

Equally important to data is time and money, and two articles explore the use of Earned Value Management (EVM) data to ensure both are optimized for project success. Through real project data, Walt Lipke assists software professionals by analyzing the predictive capabilities of EVM techniques in *Project Duration Forecasting: Comparing Earned Value Management Methods to Earned Schedule*. In *The Two Most Useful Earned Value Metrics: The CPI and the TCPI*, Quentin W. Fleming and Joel M. Koppelman describe the use of EVM data as a tool to predict needed performance levels for achieving financial success.

This issue also addresses ways to gain customers and then keep them happy through producing quality products. In *Certifications Help Organizations and Clients*, longtime CrossTalk contributor George Jackelen offers insights, for requestors and prospective bidders alike, as to the value of certifications in government Requests for Proposals. In *Using Software Quality Methods to Reduce Cost and Prevent Defects*, Rick Spiewak and Karen McRitchie offer a proactive and practical best practices framework for software construction, leading to better results, lower costs, and less developmental mishaps.

In the spirit of the holidays, please accept the December issue as our gift to you from the CrossTalk family. We hope it assists in making 2009 the best year ever, and we wish you and your family peace and prosperity for years to come.



Kasey Thompson
Publisher

A Different Kind of Web-Based Knowledge Management: The DTRA Acquisition ToolBook

Dr. Joseph P. Avery
Defense Threat Reduction Agency

Knowledge management (KM) is composed of practices deployed by organizations to identify, create, represent, classify, and disseminate knowledge for reuse, awareness, and learning to the benefit of information users. This article demonstrates the practical integration of the principles of KM and business processes by the Defense Threat Reduction Agency (DTRA). In this example, a technology-centric approach to knowledge sharing and utilization was adopted to design a simple Web-based system that provided highly needed "how-to" and reference information to DTRA acquisition professionals. The Acquisition ToolBook's successful development and deployment effectively integrated KM with internal process management, and it permitted a systemic review of the acquisition process for ineffective procedures and policies.

The idea for the Web-based DTRA Acquisition ToolBook[1] originated as a result of an information environment characterized by acquisition task and process information that was scattered throughout a myriad of DTRA Web sites as well as shared and private drives—or the information was simply not available in any capacity. This unfavorable environment was exacerbated by the DTRA being the merged product of five different defense agencies and programs. Like similar government offices, the DTRA was a hotbed of hide-and-seek information hoarding that was not conducive to efficient acquisition operations. Searching for acquisition data was becoming so difficult and time-consuming that it periodically exceeded the anticipated time for actual task completion. The DTRA had to develop a single and easily accessible, centralized, and functionally based repository of approved information, documentation, procedures, references, and processes. As well, it had to be available to all acquisition professionals, on a single page, located on the agency's main portal.

The ToolBook is not a large, DoD-wide acquisition system such as the previous Acquisition Deskbook, the current Acquisition Knowledge Sharing System, or the future Big A[2] DoD Acquisition Portal. Those Big A portals serve a broader purpose of acting as comprehensive repositories of acquisition information and collaboration. In the trenches, though, project managers are looking for smaller, simpler, and faster portals of information that quickly offer a how-to and the reference information needed to perform the various complex acquisition tasks without extensive data mining and infinite search activities. The ToolBook information environment was designed to make information easily found and accessed through a single location on the agency-level enterprise information system. More importantly, this micro-level site provides important agency-specific acquisition information and processes. The ToolBook serves as the agency's graphic interface, portraying the entire agency acquisition process represented through 24 activity boxes of related acquisition information and tasks. Every government agency could easily have a similar system.

The Blueprint to an Effective Information Environment

The ToolBook not only provides needed acquisition information, but it also includes a detailed process map of required acquisition tasks to guide the agency's acquisition professionals. Smaller, simpler, and faster were the hallmarks of the successful acquisition portal. In the ToolBook's development, users new to defense acquisition *tested* the system. Their positive feedback proved what the DTRA was aiming for: The ToolBook was successful in walking them through the tasks and activities required of the acquisition effort, and then gave them the tools, examples, forms, and references to do the job. In elevating the utility of KM, the ToolBook integrates both an extensive library of easily accessible acquisition how-to and reference information with acquisition processes and procedures. It merged the *what you need to do* with the *how and when to do it* information.

The ToolBook is based upon an integration of Microsoft SharePoint, Adobe Flash, and Microsoft .NET application software tied to a Structured Query Language data server. This combination facilitates simplicity, speed of access, and use, and provides system flexibility with a broad array of technical features beneficial to system users. By preventing infinite search activities, the ToolBook improves the speed and effectiveness of the user's acquisition task completion. The critical acquisition information provided by the ToolBook was tailored to meet the information needs of program and project managers. However, it also benefits contracting officer representatives, contract specialists, and program analysts by assisting them in the performance of their specific acquisition and procurement functions.

The ToolBook represents a merger of KM, process management, and operational simplicity. Personnel cannot access the information needed if it is too difficult to locate. Whether designing a local information system or a DoD-wide information portal, the fundamental principles of successful Web-based KM systems are the same:

1. Minimize bells and whistles and maximize quick access and simplicity of operation.
2. As the level of site complexity and menus rise, the level of user utility diminishes.
3. Needed information should be no more than three-to-five mouse clicks to user acquisition, with three being the technical objective.
4. Keep the site menu structure as shallow as possible.
5. A graphics-based system is normally more user-friendly than a text-based system, and a duplex system (a system that uses both text and graphic-based methods to retrieve information) can be more effective than a graphics-based system alone.
6. Focus system design and technical architecture on speed, easy access, and simplicity.
7. Accurate and intuitive titling of data descriptors, menus, titles, or entry points is extremely important.
8. Organize information by process, activities, functions, and organization (as appropriate for your needs).

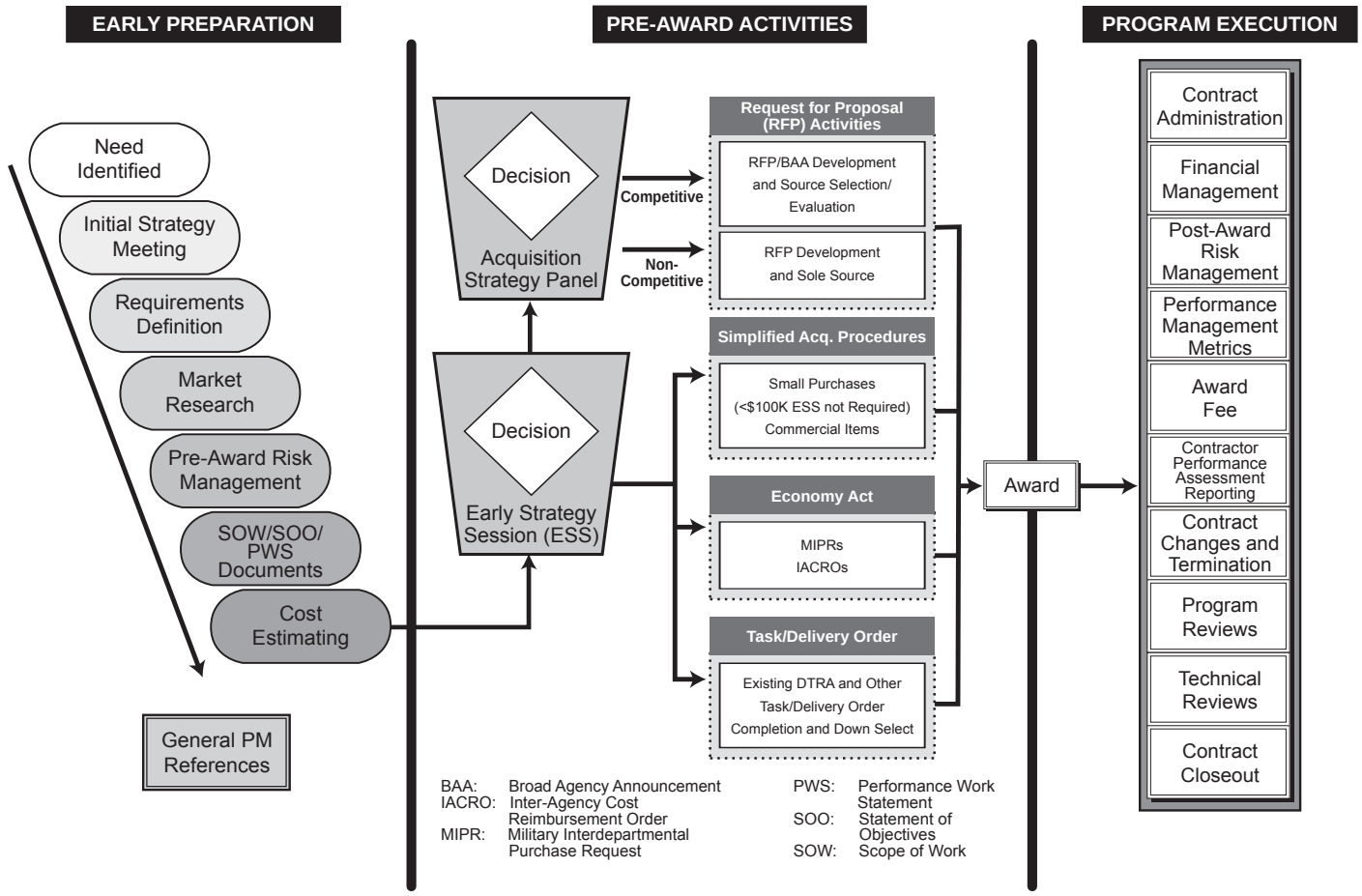


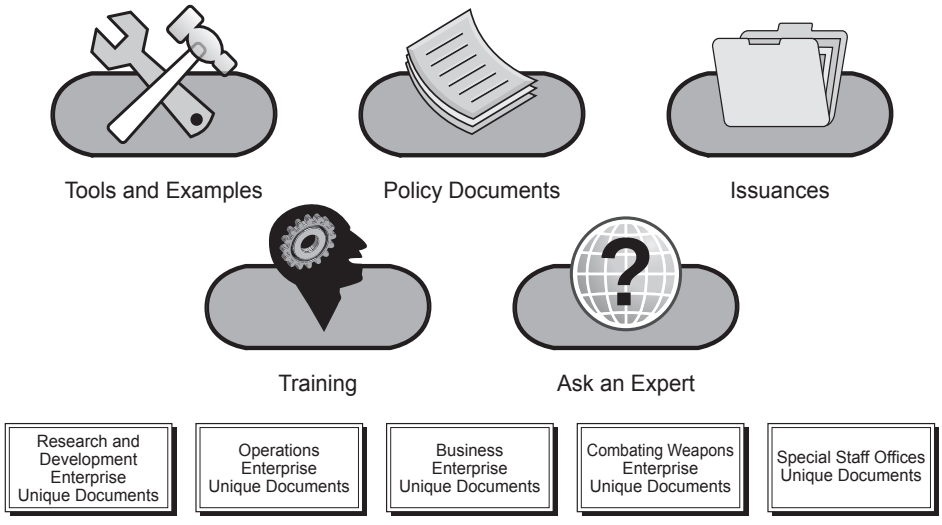
Figure 1: *The DTRA Acquisition Process*

ToolBook Structure

In this particular architectural design, the ToolBook was structured to follow the DTRA acquisition process from program start to program closeout activities (see Figure 1). The site's home page is divided into three broad phases: Early Preparation, Pre-Award Activities, and Program Execution. Early Preparation contains the initial activities required for up-front acquisition project planning and organization. The Pre-Award Activities section includes all follow-on acquisition and contractual efforts to get the acquisition awarded and on-contract. The Program Execution section contains information on the post-award phase, which includes program management (PM) and oversight activities required to administer and execute a successful program. The ToolBook home page graphic portrayal of the DTRA acquisition process is organized into 24 activity boxes that form a logical progression of the work activities required to get an acquisition effort on-contract and executed. There is also one box entitled *General PM References* that contains broad-based or overarching documents that do not fit into any one activity box category. Although the ToolBook is primarily a graphics-based acquisition portal, it is actually composed of a duplex architecture that can use a graphically-based methodology to search and retrieve data or a text-based library view that can quickly locate and more effectively display related task data. The choice of method used is based on the user's preference. Providing the user with information display options increases a program's utility.

There is only one main sub-level menu for each activity box in the main ToolBook that houses the majority of documents, making users no more than three mouse clicks away from most of the information they need (see Figure 2). There is also one third-level menu for unique enterprise-level documents. Within each activity box in the second-level menu are separate icons for the following six KM information areas: Tools and Examples, Policy Documents, Issuances (which contains guides, manuals, hand-

Figure 2: *The Sub-Level Menu for When A User Need Is Identified*



books, etc.), Training, Ask an Expert, and Enterprise-Unique Documents.

The ToolBook uses a *progressive information* approach to information classification and management. For example, if a project manager is unfamiliar with award fee contracts and requires information on how to write an award fee plan, the ToolBook offers a progressive level of knowledge to help the user get the job done. First, the user would select the Award Fee activity box. When the second-level menu appears, the five main icons provide a graduated pyramid level of information. The Training icon would provide the user with basic information on the concepts, responsibilities, and requirements of award fee contracts and issues. If more detailed information is required, the Issuances icon—which includes an array of in-depth guides, manuals, handbooks, standard operating procedures, and standard operating instructions—will provide a multitude of detailed information on the subject. Once training and/or detailed information is accessed on the subject, the user can select the Tools and Examples icon that provides the actual examples, checklists, and templates needed to help complete the task at hand. The Policy icon provides any relevant policy memoranda on the subject.

As an avenue of last resort, the ToolBook also features a sophisticated Ask an Expert capability that permits users to send acquisition-related questions to agency experts on the subject. For enterprise-unique processes, procedures, and instructions, users can also access their own enterprise's menu of key documents managed by each enterprise. The ToolBook also includes a directory of Internet links to nearly all key agency and DoD acquisition references as well as to Web pages explaining how to perform subsidiary tasks (such as the completion of travel forms required for the Defense Travel System). The ToolBook also supports a document search function and a library view capability that can simultaneously display documents by each category (for a particular activity box) for all documents.

Pros and Cons

The ToolBook system incorporates numerous advantages to both users and system administrators. It is designed for a low user investment in time and training, and also for low administrative burden. The Microsoft SharePoint 2007 architecture is easy for system administrators to manage, and offers powerful features. With some customization during the development process, it is easy for content managers to load document files and links into the ToolBook library. Adding, deleting, and modifying documents is a simple process. Formal user training classes are not required; a narrated internal virtual tour movie provides users with an overview of the entire ToolBook site. After an initial promotional campaign and scheduled system demonstrations, the site is ready for full operation upon release. Although it would be recommended to split the responsibilities of system administrator/developer and content manager, the DTRA ToolBook development, administrator, and content management tasks are assigned to one individual. Furthermore, the Ask an Expert function is also managed by the system administrator. Finally, system capability is easily expandable and the initial system development cost is low using proven software such as Microsoft SharePoint, Adobe Flash, and Microsoft .NET programming.

Like similar systems, there are some drawbacks. System data content must be reviewed for validity and utility, and to ensure that it includes updated information at least every three to six months. This could require the individual reassessment of hundreds of documents quarterly if they are not linked to golden sources[3]. Long-term system maintenance support will be required from either internal IT resources or an outside contractor. Periodic changes may be needed that require programming modifications, and future updates and development efforts will require IT support. Additionally, some users may have difficulty locating needed information if they do not have a minimum understanding of the Federal Acquisition Regulations process. The content manager may have to place a document in more than one activity box, resulting in some redundancy, but reducing search time.

Conclusion

The *Little A* principles of acquisition KM appear to apply to Big A acquisition portals. Both have a specific set of users that demand similar attributes regarding system operability: Operational simplicity, swift data location and extraction, and a logical taxonomy and data organization scheme to find and manipulate acquisition data. The fusion of the key principles of KM and specific organizational processes represent a merger of KM, process management, and operational simplicity—the foundational triad of successful user information systems. The DTRA Acquisition ToolBook has effectively managed to integrate the positive elements of portal and process development to the benefit of its acquisition workforce.◆

Notes

1. Any military or civilian government agency interested in developing their own Acquisition ToolBook can arrange a ToolBook briefing and demonstration at the DTRA by contacting Dr. Avery.
2. For those not in the acquisition business, *Big A* addresses issues such as requirements generation, program and budgeting, sustainment, development, production, strategic planning, major milestone processes, and the procurement process. *Little A* is procurement or acquisition in its narrowest sense.
3. Golden sources are those that are automatically updated by the source organization that either created or is responsible for updating the document (as required).

About the Author

Joseph P. Avery, Ph.D., is the DTRA's acquisition program manager for the Acquisition Web ToolBook and manager of acquisition and program management training with 31 years of military, federal, and defense contractor service. In 2008, he was awarded the DTRA's annual Director's Award for Acquisition Management Excellence. Avery has served as deputy and acting chief of the F-16 Fighter Production Operations Division, the B-2 Bomber avionics Acquisitions Officer (AO); the Maverick tactical air-to-ground missile AO, an International Politico-Military Affairs officer, and as a researcher for the AF Institute for National Security Studies. Avery has also been an assistant professor of government, foreign, and national security affairs at the USAF Academy and an associate professor of defense and aerospace studies at the University of North Carolina, Chapel Hill. He is a Level III-certified program manager and has a doctorate in political science and public policy, master's degrees in business administration and criminal justice management, and a bachelor's degree in political science and public safety administration.

DTRA
Phone: (703) 767-4596
E-mail: joseph.avery@dtra.mil

The Defense Technical Information Center: Information for the Defense Community

Sandy Schwalb
Defense Technical Information Center

We all seem to be doing more with less these days. Take a few minutes to learn about what is available at the Defense Technical Information Center (DTIC), an organization that can save you time and money. The DTIC offers a world of information at your fingertips, whether you use a desktop or a laptop. The DTIC has information that is from the defense community, about the defense community, and for the defense community.

The DTIC is currently the largest central resource available for DoD and government-funded scientific, technical, engineering, and business-related information[1]. For more than 60 years, the DTIC has provided warfighters, engineers, researchers, scientists, and those in laboratories and universities access to more than 2 million publications covering 250 subject areas. Approximately 100 Web sites are designed, hosted, and maintained by the DTIC for other DoD agencies and programs. The DTIC also manages 10 Information Analysis Centers (IACs), which locate, analyze, and provide scientific and technical (S&T) information in specialized subject areas.

The DTIC—a DoD field activity within the office of the Under Secretary of Defense for Acquisition, Technology and Logistics that reports to the Defense Research Engineering Director—is one of several organizations whose work reaches across all segments of the DoD.

Why Use the DTIC? Why Not?

The Information Age is also the era of reduced budgets and fewer personnel, where doing more with less is an overused (but true) expression. This is certainly a reality in the federal government. The DoD Scientific and Technical Information Program Directive 3200.12 calls for the need to reduce unnecessary S&T expenditures. This is where DTIC comes in. Using the DTIC's resources can help:

- Leverage the multi-billion dollar investment in DoD research and engineering.
- Prevent unnecessary or redundant research.
- Get DoD S&T information into the hands of the *right* people in the defense community.
- DoD researchers and decision makers turn DTIC data into value-added knowledge for ongoing and new efforts.
- Offer up-to-date electronic information to the defense community using *push technology*.
- Provide information support to the federal and contractor communities.
- Build on prior knowledge.

Why *reinvent the wheel*? Sharing resources can be a boon to engineers, researchers, students, and anyone who needs information to produce new and better research that can lead to new and better technologies. We want to ensure that our collection is as complete as possible, allowing researchers to find information, determine if money has been spent on that kind of effort in the past, and learn about those project outcomes.

"Why reinvent the wheel? Sharing resources can be a boon to engineers, researchers, students, and anyone who needs information to produce new and better research that can lead to new and better technologies."

One Site, One Source

The December 2007 CrossTalk Web Sites section highlighted one of our databases:

> The Public Scientific and Technical Information Network (STINET) is available to the general public, free of charge. It provides access to citations of unclassified unlimited documents that have been entered into the DTIC's Technical Reports Collection, as well as the electronic full-text of many of these documents. Public STINET also provides access to the Air University Library Index to military periodicals, staff College Automated Military Periodical Index, DoD Index to Specifications and Standards, and Research and Development Descriptive summaries. [1]

With the advent of the DTIC's redesigned Web site and search systems <www.dtic.mil/dtic/search/tr/>, the acronym STINET is no longer used for our public site. The good news is that all of the information in our collection (and then some) is still offered.

As a result of the rapid growth of DTIC capabilities and inclusion of new information audiences, the DTIC's administrator, R. Paul Ryan, directed the staff (in 2007) to create a more structured (simpler) information delivery approach. The goal was met in mid-2008 when the DTIC launched a new user interface, DTIC Online <www.dtic.mil>, which offers a one-site, one-source location for DoD S&T information.

DTIC Online provides free access to citations of public release reports that describe the progress or results of research efforts and other S&T information held by the DTIC. Many of these documents are available in full-text and can be downloaded. A key feature of the new site is the ability to search more databases using DTIC's MultiSearch Enhanced <http://multisearch.dtic.mil>. This tool, a portal to the *deep-Web* for government S&T information, searches content below the *surface* Web for information not accessible through commercial and government search engines. This search feature assists the DoD community in accessing S&T information over a wide range of DoD and commercial sources. DTIC customers can now search an estimated 3.5 million documents, from more than 50 national and international sources.

New to this public DTIC Web site is the Interest Areas section, which provides

access to a broad range of contacts, associations, blogs, conferences, and research institutions appropriate to S&T research communities. Each interest area has a DTIC staff member who manages the specific page <www.dtic.mil/dtic/communities/>. Feedback and comments are welcome: <ref@dtic.mil>.

The DTIC is currently assessing various avenues as we look to revamp our access-controlled site, available to our registered customers (see the registration section).

What Is Available?

You can find documents on topics ranging from acquisitions to zeta functions:

- **Public Technical Reports.** This database contains more than 2 million reports in print and non-print formats (software, datafiles, databases, and video recordings) conveying the results of defense-sponsored research, development, test, and evaluation efforts. It includes journal articles, DoD-sponsored patent applications, studies, analyses, open-source literature from foreign countries, conference proceedings, and theses. Between 30,000 and 35,000 new documents are added annually.
- **Research Summaries.** This database contains descriptions of DoD research in progress, providing information on technical content, responsible individuals and organizations, principal investigators, and funding sources[2]. The collection consists of approximately 309,000 active and inactive summaries from 1965 to the present.
- **Independent Research and Development (IR&D).** This database contains more than 173,000 descriptions (dating back to the mid-'70s) of R&D projects initiated and conducted by defense contractors independent of DoD control and without direct DoD funding. On average, in excess of 2 billion dollars worth of IR&D projects are annually submitted to the DTIC. The database includes basic and applied research and technology development efforts as well as systems and concept formulation studies. Defense contractors and potential contractors are encouraged to submit project descriptions to the IR&D database. Accessible only to DoD and select U.S. government organizations, the proprietary IR&D information is used to identify contractors with expertise in areas of interest to the DoD and to avoid DoD duplication of industry research and development efforts.
- **Technical Reports Automated Information List.** A free, publicly available electronic mailing list that, every two weeks, disseminates citations to the DTIC's recently added unclassified, unlimited technical reports.

A Leader in Utilizing the Web

As a center of excellence for information storage and retrieval, the DTIC has been able to advise DoD components concerning policy, law, best practices, and security strategies that relate to the transmission and use of all types of information. The DTIC offers full-service Web support, an established Web architecture, and customer liaisons. The DTIC hosts more than 100 Web sites, such as the Joint Chiefs of Staff, the Defense Prisoner of War/Missing in Action Office, and the Federal Voting Assistance Program.

"As a center of excellence ... the DTIC has been able to advise DoD components concerning policy, law, best practices, and security strategies that relate to the transmission and use of all types of information."

To Distribute or Not to Distribute

While there is much publicly accessible material in the DTIC collection (almost one-half of the DoD's technical reports are publicly available the day they are published), some information has security classifications. The DoD's S&T information is always categorized (or *marked*, the term used in the defense community) by the office that originates the document. This marking determines how and with whom the information can be shared. Some information is marked to protect national security. DTIC databases contain such *classified* information that may be marked confidential or secret.

DTIC databases also contain information that, although not classified, is still sensitive for various reasons. These documents are marked to show why the information is sensitive and to whom the document can be distributed. Such documents are referred to as *unclassified*, *limited*. Information that is neither classified nor limited (but can be released to the public) is referred to as *unclassified*, *unlimited*. The DTIC's collection is comprised of 51 percent unclassified, unlimited; 40 percent unclassified, limited; and 9 percent classified information.

Registration Is the Key

The first step in ensuring that you can get the information you need from us is by registering for services at <www.dtic.mil/dtic/registration>. Access to DoD classified and unclassified, limited information is controlled through this registration process. A variety of secure DoD Web sites can be accessed by authorized users. While our primary customers are those who have a legitimate business relationship with the DoD and largely include the military and defense contractors, there are other categories of customers.

Who uses DTIC information? Here is a snapshot of our registered customers:

- Acquisition instructors.
- Active duty military.
- Congressional staff.
- Directors of corporate relations.
- DoD contractors.
- Faculty at military schools.
- Historians.
- Logistics management specialists.
- Quality assurance specialists.
- Small business owners.
- Security managers.
- Software engineers and developers.

A Wealth of Information

The DTIC has a wide range of information products relating to S&T planning, budget, financial, R&D descriptions, management, test and evaluation, research results, training, law, command histories, conference proceedings, DoD Directives and Instructions, foreign documents and translations, journal articles, management summaries, security classification guides, technical reports, and summaries of works in progress.

Why does the DTIC get this information? It is required by DoD Instruction 3200.14, which mandates that DoD research, including research done in-house and/or by contractors and grantees, should be part of the DTIC collection. In other words, if there is great technology in the DoD, the DTIC should have that information for others to use and build upon. The

material comes from many sources:

- DoD organizations (civilian and military) and DoD contractors.
- U.S. government organizations and their contractors.
- Non-profit organizations working on DoD scientific, research, and engineering activities.
- Academia.
- Foreign governments.

Specialized Information Solutions

Another facet of DTIC activities is the management and funding of 10 contractor-operated joint service-oriented IACs <http://iac.dtic.mil>. Chartered by the DoD, IACs locate and analyze S&T information for customers in specific subject areas. Staffed by experienced technical area scientists, engineers, and information specialists, the IACs have comprehensive knowledge bases which include historical, technical, scientific, and other data collected on a worldwide basis. Many of the IACs' products and services are free and include announcements of pertinent reports in the particular IAC's field of interest, authoritative bibliographic search reports, the latest scientific and engineering information on specific technical subjects, consultation with or referral to world-recognized technical experts, and the status of current technologies. The 10 DTIC-managed IACs (as of September 2008) are:

- AMMTIAC: Advanced Materials, Manufacturing, and Testing.
- CBRNIAC: Chemical, Biological, Radiological, and Nuclear Defense.
- CPIAC: Chemical Propulsion.
- DACS: Data and Analysis Center for Software.
- IATAC: Information Assurance Technology.
- MSIAC: Modeling and Simulation.
- RIAC: Reliability.
- SENSIAC: Military Sensing.
- SURVIAC: Survivability/Vulnerability.
- WSTIAC: Weapons Systems Technology.

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Notes

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About the Author

Sandy Schwalb is the DTIC Public Affairs Officer. Previously, she was a member of its marketing team. Schwalb has served as a speechwriter (U.S. Government Printing Office), director of government relations (Special Libraries Association), and staff assistant/legislative correspondent (former U.S. Senator Charles McC. Mathias, Jr.–Maryland). She has written and spoken extensively about defense, U.S. government, and library/information issues.

DTIC
8725 John J. Kingman RD
STE 0944
Fort Belvoir, VA 22060-6218
Phone: (703) 767-9205
E-mail: sschwalb@dtic.mil

Project Duration Forecasting: Comparing Earned Value Management Methods to Earned Schedule

Walt Lipke
Oklahoma City Chapter of the Project Management Institute

Earned Value Management (EVM) methods for forecasting project duration have been taught in training courses and used by project managers for four decades. These EVM methods are generally considered to be accepted practice, yet they have not been well-studied and researched as to their predictive capability. Using real project data, this article examines and compares the duration forecasts from four EVM methods to the Earned Schedule (ES) prediction technique.

The concept of ES was introduced in the spring of 2003, demonstrating the possibility of describing schedule performance in units of time [1]. ES facilitates time-based analysis of the schedule, employing uniquely the EVM measures of cost. One year subsequent to the publication of ES, the concept was extended to include project duration forecasting. The article "Further Developments in Earned Schedule" [2] put forth two equations for forecasting the final duration for a project, one of which is used in this study.

From 2004-2007, two independent papers were published investigating the capability of the ES forecasting method. One paper written by Lew Hecht describes, positively, the usefulness of ES in a case study of a single U.S. Navy project [3]. The second is a comprehensive examination of the capability of ES. The research team of Vanhoucke and Vandevoorde applied a simulation method for assessing the performance of two EVM-based methods and ES in forecasting project duration [4]. A portion of the Vanhoucke and Vandevoorde paper has been updated and published in the Winter 2007-2008 issue of *The Measurable News* [5][1]. The conclusion from both is that: "The results ... confirm ... that the Earned Schedule method outperforms, on average, the other forecasting methods."

Although the results of the research performed by Vanhoucke and Vandevoorde are well regarded, there remains the question of whether the simulation technique is truly representative of real project circumstances. Likewise, the case study testimonial, while strongly supportive of the use of ES indicators and forecasting, is inconclusive in broadly validating the concept. Beyond the recognized shortcomings of the aforementioned studies, it has recently been recognized that four frequently used EVM-based methods of duration forecasting have not been compared to ES. This research is focused to overcome the identified gaps. Real data from 16 projects is used to analyze the respective forecasting capabilities of the overlooked EVM methods along with ES.

This article begins by defining the pertinent elements of the EVM and ES methods. Building on this foundation, the forecasting equations are presented. Next, the hypothesis of the analysis is described. Then the computations needed to perform the analysis and evaluation are outlined. The project data is then characterized and results from the computations and analysis are discussed. Finally, conclusions are drawn.

EVM Duration Forecasting

An understanding of EVM and its terminology is assumed in this article. For convenience, the EVM terminology used to portray project status and forecast final duration is defined in the following:

- Planned Value (PV).
- Earned Value (EV).
- Budget at Completion (BAC), which is the planned cost of the project.
- Performance Measurement Baseline (PMB), which is the cumulative PV over time.
- Independent Estimate at Completion (IEAC(t)), which is the forecast final duration.

Four EVM duration forecasting techniques have been commonly applied over the last 40 years to predict project completion dates. These methods have the following basic form:

Duration Forecast = Elapsed Time + Forecast for Work Remaining
IEAC(t) = AT + (BAC - EV) / Work Rate

where

AT = Actual Time (the duration elapsed to the time at which PV and EV are measured)
BAC - EV is commonly termed the work remaining
Work Rate is a factor which converts the work remaining to time, the duration forecast for the remaining work

The four Work Rates commonly applied are:

1) Average Planned Value: PVav = PVcum/n
2) Average Earned Value: EVav = EVcum/n
3) Current Period Planned Value: PVlp
4) Current Period Earned Value: EVlp

where

PVcum = Cumulative value of PV
EVcum = Cumulative value of EV
n = Total number of periodic time increments of project execution within AT

The EVM forecasts of final duration, IEAC(t), are associated with the Work Rate employed and identified in the remainder of this article as follows:

1) PVav: IEAC(t)PVav
2) EVav: IEAC(t)EVav
3) PVlp: IEAC(t)PVlp
4) EVlp: IEAC(t)EVlp

ES Duration Forecasting

A recent extension to EVM, ES, has emerged to provide reliable, useful schedule performance management information. In brief, the method yields time-based indicators, unlike the cost-based indicators for schedule performance offered by EVM.

Figure 1 is an illustration for understanding the concept. The ES measure identifies when the amount of EV accrued should have occurred. As depicted by the diagram, this is the point on the PMB where PV equals the EV accrued. The vertical line from the point on the PMB to the time axis determines the *earned* portion of the schedule. The duration from the beginning of the project to the intersection of the time axis is the amount of ES.

With ES and AT defined, the schedule performance efficiency is formulated as depicted in Figure 1, Schedule Perfor-

mance Index (time) [SPI(t)] = ES/AT. From EVM, final cost may be forecast from the formula, IEAC = BAC/Cost Performance Index (CPI); CPI = EV/AC, where AC is the actual cost. In an analogous manner, final duration is forecast from IEAC(t)es = PD/SPI(t), where PD is the planned duration for the project and IEAC(t)es is the ES forecast of final duration.

Discussion of Forecasting Methods and Study Considerations

The objective of the study is to investigate and understand the forecasting capability of the five methods, four from EVM and one from ES. By inspection, it can be deduced that the EVM Work Rates have mathematical failings which affect their performance.

When the project executes past its planned duration, PVcum is equal to its maximum value, BAC, and is invariant thereafter. Thus, the PVav Work Rate becomes PVav = BAC/m, where m is a number larger than the planned number of time periods for the project. Obviously, as m becomes larger, PVav is decreasingly smaller, thereby causing the work remaining forecast to be longer than its planned time.

The situation for the PVlp Work Rate is more severe. After the planned project duration has passed, there are no periodic values of PV, thereby making the computation of IEAC(t)PVlp indeterminate. These observations are excluded from the study because it may be that IEAC(t)PVlp is a good predictor otherwise. A tenet of the study is to provide each method a reasonable opportunity to show well, despite the known limitations.

The two Work Rates, EVav and EVlp, do not normally have indeterminate calculation conditions. There is, however, one exception of when a period elapses with no EV accrued; this condition may occur for smaller projects which assess their status weekly. When EVlp is equal to zero, IEAC(t)EVlp cannot be calculated. Just as for PVlp, the condition is accommodated in the study so as to not discredit the overall forecasting performance of EVlp. When an anomalous instance is encountered, the forecast for the previous valid observation is used.

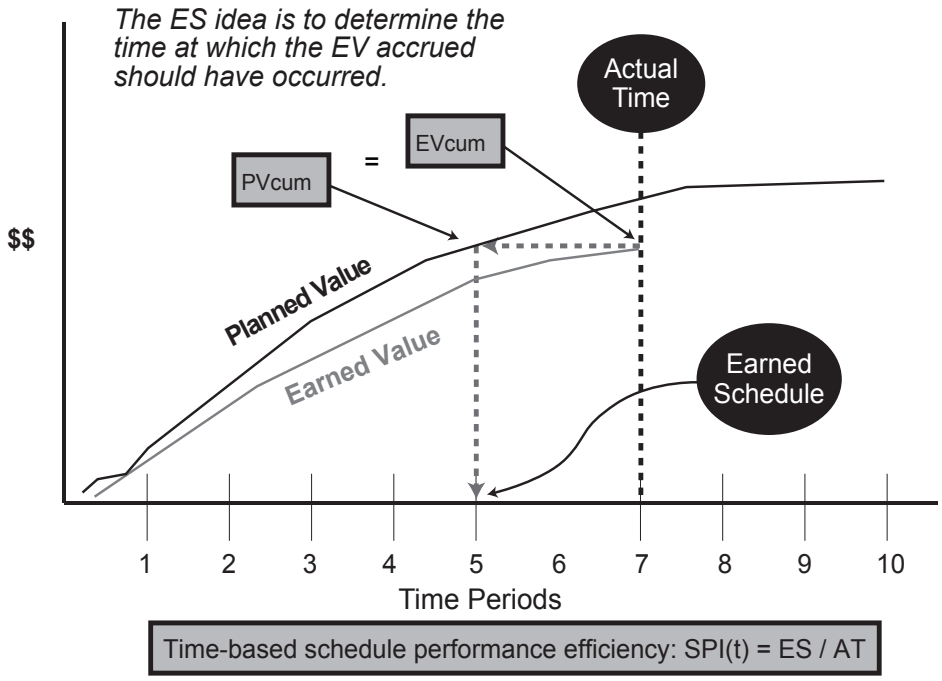


Figure 1: *The Earned Schedule Concept*

The forecasting from ES does not experience indeterminate calculation conditions. A common positive characteristic of all of the methods, with the exception of IEAC(t)PVlp, is that they converge to the actual duration. The predictive capability of the four EVM-based methods in this study may be superior to the two tested by Vanhoucke and Vandevoorde [4,5]; those methods did not necessarily correctly calculate the actual outcome duration at completion.

Study Hypothesis and Methodology

The conjecture to be examined in the study is that ES provides a better forecasting method of final project duration than the four methods cited previously for EVM. To make a determination concerning this conjecture, the extreme case will be examined and tested. The test is constructed to show that the EVM methods, as an aggregate, produce better forecasts than ES does. If the EVM methods are shown to be superior to ES, it will not be known which one of the EVM methods is better. Thus, if this is the determination, further examination will be necessary to understand the circumstances for selecting the appropriate EVM forecasting method.

The hypothesis from the preceding discussion is formally defined (by [6]) as follows:

Ho: EVM methods produce the better forecast of final project duration
Ha: The ES method produces the better forecast of final project duration

where

Ho: The null hypothesis (i.e., the statement to be validated) and Ha is the alternate hypothesis.

The statistical testing is performed using the Sign Test applied at a 0.05 level of significance [7]. Assuming each of the five methods has an equal probability of success, the probability for each trial is 0.8.

Data from 16 projects is used for generating the forecasts from each of the methods. These forecasts are then tested and analyzed. The test statistic for the hypothesis test is computed from the number of times the EVM methods are observed to yield the better forecast. Thus, for each testing condition applied,

Table 1: *Schedule Performance for Projects in the Data Set*

	Schedule Performance															
Project	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Planned Duration	21m	32m	36m	43m	24m	50m	46m	29m	45m	44m	17m	50m	81w	25w	25w	19w
Actual Duration	24m	38m	43m	47m	24m	59m	54m	30m	55m	50m	23m	50m	83w	25w	22w	13w

Legend: m = months w = weeks

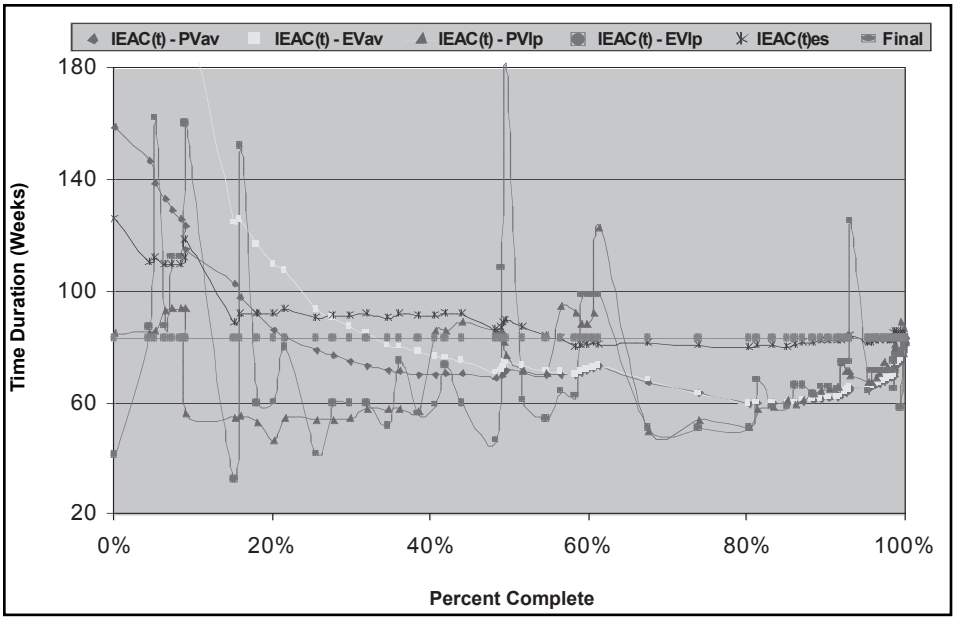


Figure 2: *Final Duration Forecasting Comparisons*

the maximum number of successes for the EVM methods is 16. When the EVM methods successes are fewer than 10, the test statistic has a value in the critical region (< 0.05). A value in the critical region indicates that there is enough evidence to reject the null hypothesis. In clearer language, this test result shows that the EVM methods do not produce duration forecasts better than those from ES. A test statistic value outside of the critical region is the converse; that is, there is not enough evidence to reject the null hypothesis.

The test statistic is determined from the ranking of the standard deviations for each of the forecasting methods for each project. The standard deviation is calculated from the differences between the forecast values computed at the project status points and the actual final duration as defined:

$$\sigma_m = [\Sigma (FV_m(i) - FD)^2 / (n-1)]^{0.5}$$

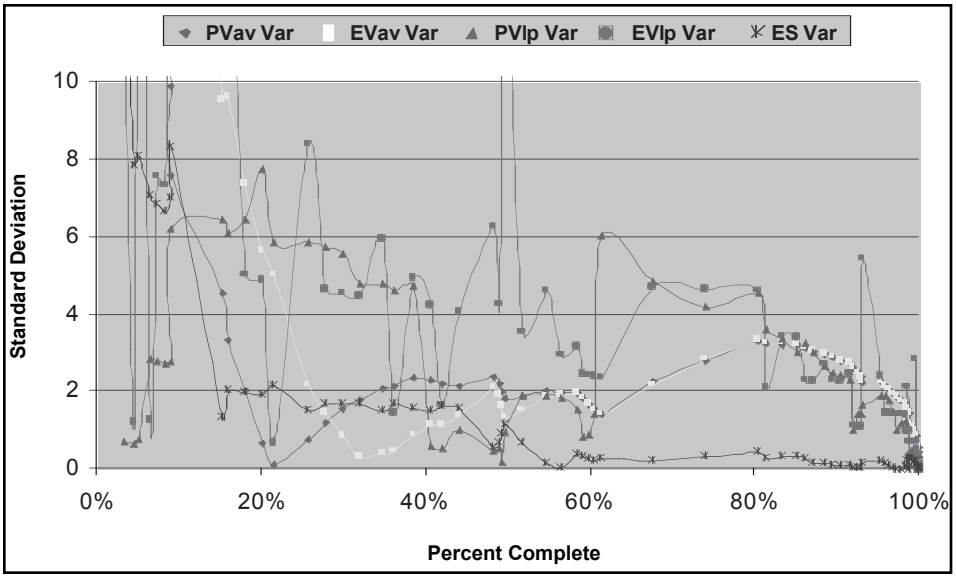
where

σ_m = Standard deviation for forecasting method m
$FV_m(i)$ = Forecast value for method m at status point (i)
FD = Actual final duration
n = Number of status points
Σ = Summation over a specific set of status points

The smallest value for the standard deviation indicates the best forecast produced. There are five forecasting methods ranking from 1 to 5, with 1 associated with the lowest and 5 the highest value of standard deviation. The ranking of the methods is performed for the 16 sets of project data. The number of times the rank of 1 occurs (without ties between the EVM methods) determines the test statistic value. By using the ranking approach, the unit for the periods (e.g., months, weeks) can be different between projects; the ranking of the five methods is performed separately for each project.

To understand whether a particular method is better for early, middle, late, or overall forecasting, the projects are analyzed and tested for specific regions of performance. Groupings are formed using the observations within various percent complete ranges to make the determinations: early (10-40 percent), middle (40-70 percent), late (70-100 percent), overall (10-100 percent). Additionally, other ranges are used to determine if one of the methods converges to the actual final duration more rapidly than the others, thus being better for a portion of the forecast (but not necessarily superior overall). The ranges used for this purpose are: 25-100 percent, 50-100 percent, and 75-100 percent.

Figure 3: *Time Forecasting Standard Deviation Comparisons*



Data Discussion

A total of 16 projects are included in the study. Twelve (1 through 12) are from one source with four (13 through 16) from a second. The output of the 12 projects is high technology products. The remaining four projects are associated with IT products.

The primary data requirement is that the projects used in the study have not undergone any re-planning. The requirement is necessary to be able to discern the ability of the forecasting methods without having outside influence. All 16 projects performed from beginning to completion without having baseline changes.

Table 1 (see page 11) illustrates the schedule performance of the projects in the data set. The 12 high technology projects are measured in monthly periods whereas the four IT projects are measured weekly. Two projects were completed early, three on time, and the remaining 11 later than planned.

Results Analysis

To begin the analysis, it is instructive to view the graphs from a single project (Project #13). The first graph, Figure 2, portrays the forecasting performance of all five methods along with the horizontal line for the actual final duration. It is observed that the prediction using the PVav and EVav Work Rates behave in a much less erratic manner than do the forecasts from the current period rates, PVlp and EVlp. The forecast from ES is seen to be much better than any of the EVM pre-

dictions, especially after the project completion point of 40 percent.

The next graph, Figure 3, portrays similar information. It contains plots of the standard deviation versus percent complete for each of the EVM and ES methods. The behavior seen in Figure 2 is amplified by viewing the standard deviation. As described for Figure 2, the average work rates are less volatile, while the current rates have large changes from one observation to the next. Again, the ES forecast is observed to be much more stable than any of the other methods. The standard deviation of the ES forecast is noticeably smaller than any of the other methods between 50 and 100 percent complete.

Figure 4 is a column graph illustrating a view intended for analyzing the forecasting behavior for early, middle, late, and overall ranges of project execution. Figure 5 is also a column graph; the ranges applied (25-100 percent, 50-100 percent, 75-100 percent) are used to determine the behavior of the various methods regarding the rate of convergence to the final duration.

For both Figures 4 and 5, it is clearly seen that the current period methods are generally more volatile and that the ES method is the better predictor in every range. In fact, for this project, the accuracy of the ES forecasting method is significantly better than the EVM methods.

It was previously mentioned that, with the exception of the forecast using the PVlp Work Rate, all of the other methods converge to calculate the actual final duration. Because of this characteristic, the expectation is that the standard deviation should decrease as the completion percentage increases. This behavior is observed for ES and EVlp, but the others are nearly invariant between the 25-100 percent, 50-100 percent, and 75-100 percent ranges. Looking back at Figure 3, the convergence is seen for PVav and EVav, but it is not strongly evident until after the project has progressed past 80 percent complete.

Table 2 (see next page) is an example for the 10-40 percent completion range. It is the tabulation of the computed standard deviations for each forecasting method and their ranking for each project. From reviewing the table, an observation is made that for this completion range, the ES rank is 1 for 11 of the projects. The ES forecasting method provides the best forecasts of final duration for a large majority of the projects. Even so, it does not produce the best forecast results for every project. All seven ranges are analyzed to understand more completely how the various methods perform under different circumstances.

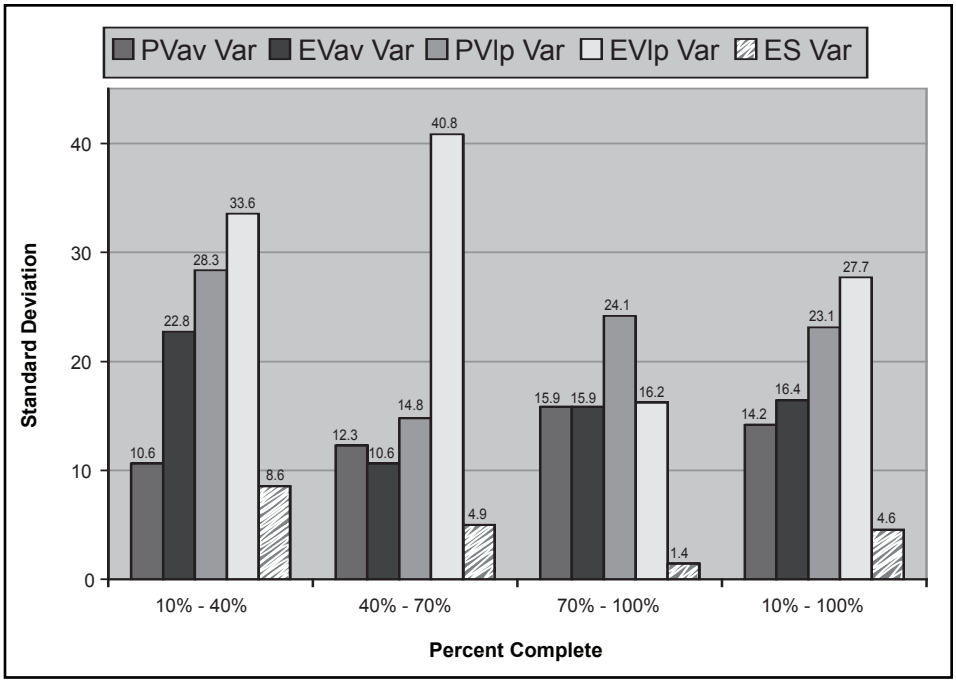
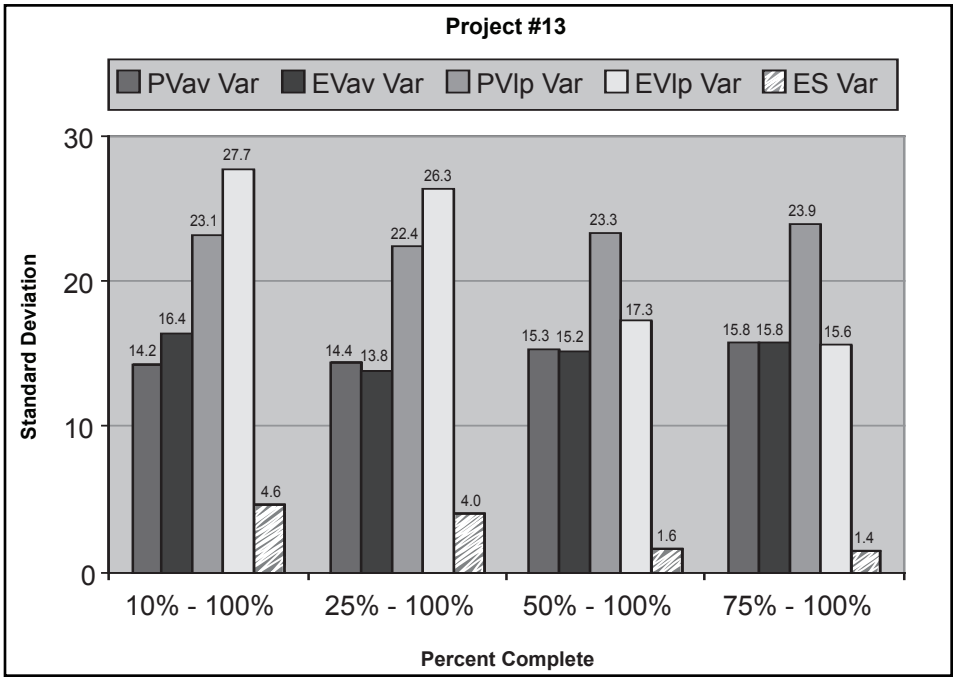


Figure 4: *Comparison of Forecasting Accuracy*

To better understand the goodness of the forecasting methods for the examined completion band, Table 3 (see next page) was created. It is a condensation of Table 2. As can be observed, the distribution of the ranking numbers is made between the various forecasting methods. In general, the sum for each of the ranks will equal the number of projects, 16. However, when there are ties, as there is for this range, one rank may total more than 16 while an adjacent rank will be equally lower. For Table 3, it is noted the sum of the 1s is seventeen, while the sum of the 2s is 15.

At the bottom of Table 3, a weighted average of the ranking distribution is computed for each of the forecasting methods. These weighted averages are then used to rank the methods for the completion range examined. Table 4 (see next page) is a tabulation of the weighted averages of the rankings for each of the seven completion ranges. For each range, the ES method has the lowest weighted average, indicating that, on average, it is the best predictor of final duration. The only challenge to ES is within the 40-70

Figure 5: *Forecasting Convergence*



Project ID		Project #1		Project #2		Project #3		Project #4		Project #5		Project #6	
		Std Dev	Rank	Std Dev	Rank	Std Dev	Rank	Std Dev	Rank	Std Dev	Rank	Std Dev	Rank
Methods	PVav	14.95	5	13.01	4	11.93	2	25.59	2	4.38	2	29.76	2
	EVav	2.65	1	9.35	2	8.28	1	48.68	4	5.82	3	42.64	4
	PVIp	5.47	2	13.62	5	77.74	5	42.77	3	8.67	4	42.11	3
	EVIp	6.00	3	12.14	3	22.38	3	103.15	5	9.89	5	263.03	5
	ES	8.28	4	4.78	1	46.76	4	14.03	1	1.88	1	3.57	1
Project ID		Project #7		Project #8		Project #9		Project #10		Project #11		Project #12	
		Std Dev	Rank	Std Dev	Rank	Std Dev	Rank	Std Dev	Rank	Std Dev	Rank	Std Dev	Rank
Methods	PVav	9.79	3	16.16	3	6.75	2	9.06	1	7.66	4	15.06	3
	EVav	6.00	2	33.17	5	15.63	3	10.55	2	6.63	3	30.49	5
	PVIp	17.95	5	20.69	4	20.80	4	39.11	4	7.70	5	9.06	1
	EVIp	15.07	4	5.69	2	525.62	5	102.21	5	6.58	2	26.86	4
	ES	4.31	1	5.09	1	3.74	1	15.22	3	4.54	1	12.49	2
Project ID		Project #13		Project #14		Project #15		Project #16					
		Std Dev	Rank	Std Dev	Rank	Std Dev	Rank	Std Dev	Rank				
Methods	PVav	10.57	2	2.36	1	15.93	3	20.18	5				
	EVav	22.78	3	5.90	5	18.12	5	17.10	4				
	PVIp	28.25	4	2.36	1	11.24	2	12.37	2				
	EVIp	33.59	5	2.49	4	16.87	4	16.49	3				
	ES	8.62	1	4.46	3	4.45	1	5.20	1				

Table 2: *Standard Deviation and Ranking for 10-40 Percent Completion Range*

percent middle range, where the weighted average of 2.063 for ES is somewhat lower than the 2.500 from PVav.

Finally, more conclusive evidence of the goodness of the ES forecasting capability is provided from the statistical hypothesis testing. Table 5 provides the compiled results from the testing analysis. In the table, the count of the rank of 1 is provided for the aggregate of the EVM methods and for ES. With the exception of one test range, ES shows to be superior to the other methods combined. In one instance, the 40-70 percent range, the number of 1s counted for EVM exceeds the number for ES. However, the value of the test statistic is in the critical region; this is enough evidence to reject the null hypothesis that the aggregate of the EVM methods is better than the ES method. Thus, from the results of the Sign Test, ES is indicated to be the better forecasting method regardless of project completion stage (early, middle, late, and overall).

Table 3: *Rank Count for Data Group, 10-40 Percent*

		Methods				
		PVav	EVav	PVIp	EVIp	ES
Count	Nr1s	2	2	2	0	11
	Nr2s	6	3	3	2	1
	Nr3s	4	4	2	4	2
	Nr4s	2	3	5	4	2
	Nr5s	2	4	4	6	0
Weighted Average		2.750	3.250	3.375	3.875	1.688
Composite Rank		2	3	4	5	1

Table 4: *Weighted Average of Ranking Results*

	Percent Complete Test Bands						
	10%-40%	40%-70%	70%-100%	10%-100%	25%-100%	50%-100%	75%-100%
ES	1.688	2.063	1.438	1.625	1.563	1.563	1.438
PVav	2.750	2.500	3.688	2.625	2.813	3.063	3.875
EVav	3.250	2.813	2.938	3.00	3.063	2.938	2.875
PVIp	3.375	3.438	3.875	3.813	3.875	3.688	3.875
EVIp	3.875	4.188	3.063	3.938	3.688	3.750	2.938

Table 5: *Hypothesis Test Results – EVM vs. ES Time Forecast*

Significance α = 0.05		Percent Complete Test Bands						
		10%-40%	40%-70%	70%-100%	10%-100%	25%-100%	50%-100%	75%-100%
Test Statistic Sign Test		0.0000	0.0267	0.0000	0.0000	0.0000	0.0002	0.0000
		Ha	Ha	Ha	Ha	Ha	Ha	Ha
Counts #1s	ES	11	7	12	11	11	10	12
	EVM	5	9	4	5	5	6	4

Hypothesis Test: Sign Test at 0.05 level of significance
Ho: The aggregate of EVM forecasts is better/the null hypothesis
Ha: ES forecast is better/the alternate hypothesis

Summary and Conclusions

Five methods of project duration forecasting were examined in this study, four from EVM and the ES technique. Performance data from 16 projects was used to assess the capabilities of the various forecasting methods. The analysis strategy segregated the project data into seven ranges of percent complete in order to isolate possible forecasting characteristics or tendencies among the methods.

Each of the methods were used to create forecasts from the project data. The standard deviation of the forecasts from the actual final duration was computed for each project, and each percent complete range was studied. The forecasting methods were then ranked from best to worst using the standard deviations.

The tabulation of best forecasts (one of the four EVM methods or ES) for each range was used to calculate the test statistic for the Sign Test. The null hypothesis—that EVM provides the better forecast—was rejected for every percent complete range examined.

Conclusively, from among the methods and data set studied, ES is shown to be the best method of forecasting project duration.◆

Acknowledgement

The project data used in this study was made available by Dr. Ofer Zwikael and Mr. Kym Henderson. I am indebted to these gentlemen for their contribution to this study.

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Note

1. While condensed, [5] is a more easily readable and accessible version of [4]. The complete article, [4], is fairly expensive, while [5] is available online at <www.pmi-cpm.org/pages/measurable_news/documents/Winter2007 2008Final5_000.pdf>.

About the Author

Walt Lipke retired in 2005 as deputy chief of the software division at Tinker AFB. He has over 35 years of experience in the development, maintenance, and management of software for automated testing of avionics. During his tenure, the division achieved several software process improvement milestones, including the coveted Software Engineering Institute/IEEE award for Software Process Achievement. Lipke has published several articles and presented at conferences internationally on the benefits of software process improvement and the application of EVM and statistical methods to software projects. He is the creator of the ES technique, which extracts schedule information from EV data. Lipke is a graduate of the DoD course for program managers. He is a professional engineer with a master's degree in physics. He is a member of the physics honor society, Sigma Pi Sigma, and the collegiate honor society, Phi Kappa Phi. During 2007, he received the Project Management Institute (PMI) Metrics Specific Interest Group Scholar Award and the PMI Eric Jenett Project Management Excellence Award, both for his leadership role and contribution to project management resulting from his creation of ES.

1601 Pembroke DR
Norman, OK 73072
Phone: (405) 364-1594
E-mail: waltlipke@cox.net

Web Sites

Earned Value Management (EVM)

www.earnedvaluemanagement.com

Learn more about the project management system that combines schedule performance and cost performance to answer the question, "What did we get for the money we spent?" The Web site describes the basic concepts of EVM: project steps earning value as work is completed, comparing Earned Value to the actual and planned costs to determine project and future performance, and measuring the physical project progress in dollars so that both schedule and cost performance can be analyzed in the same terms. The Web site also details EVM's benefits, its building blocks, its performance indices and variance, its forecasting capabilities, and ways to get your organization or business started in utilizing EVM.

Earned Schedule (ES)

www.earnedschedule.com

ES is a breakthrough analytical technique that resolves the EVM dilemma of schedule indicators providing false information for late-performing projects. It is derived from and is an extension of EVM, needing no additional data for acquiring the ES measures (just the data from EVM). Along with learning the process of using ES, this site defines ES terminology, offers links to the latest ES news, publications, and presentations, and provides a free downloadable ES calculator.

Get your ducks in a row

www.washingtontechnology.com/print/23_02/32228-1.html

To contractors and agencies, ISO certifications and CMMI ratings denote specific accomplishments in implementing methodical, disciplined processes. In his article for *Washington Technology*, Michael Hardy argues that while earning certifications is costly and time-consuming, companies cannot avoid making the investment if they expect to remain competitive. He also highlights several companies, showing both their processes in earning ISO certifications and CMMI Level ratings, and the competitive benefits those certifications have yielded.

Guide to the Software Engineering Body of Knowledge

www.swebok.org/ironman/pdf/SWEBOK_Guide_2004.pdf

For the first time, the IEEE Computer Society has established a baseline for the body of knowledge for the field of software engineering. The Guide does not claim to define the body of knowledge but rather it serves as a compendium and guide to the body of knowledge that has been developing and evolving over the past four decades. The Guide is subdivided into 10 software engineering Knowledge Areas, including software requirements, design, construction, testing, maintenance, configuration management, engineering management, engineering process, engineering tools/methods, and quality.

The Two Most Useful Earned Value Metrics: The CPI and the TCPI

Quentin W. Fleming and Joel M. Koppelman
Primavera Systems, Inc.

The Project Management Institute (PMI) has just released the 4th edition of their world standard on project management: A Guide to the Project Management Body of Knowledge. *Many new features have been added to this massive document, among them new coverage of an Earned Value metric called the To-Complete Performance Index. What is the To-Complete Performance Index and why is it important? This article describes its purpose and utility, and how it can work with the Cost Performance Index.*

Whenever a project commits to the employment of Earned Value to help manage their effort, users are suddenly inundated with a windfall of performance metrics which are available in no other project management technique. New acronyms suddenly emerge: PV, EV, AC, SV, SPI, CV, CPI, BAC, EAC, TCPI[1], and on and on. While all of these performance indicators can have value to any project, the two Earned Value Management (EVM) metrics particularly critical to projects are the CPI and the TCPI.

The CPI tells the user what has been accomplished for what has already been spent: Did the project stay within the budget, or was there an overrun? By contrast, the TCPI focuses on future work questions such as: What performance levels must be achieved on the remaining work in order to meet our financial commitment to management? While most practitioners of EV understand the utility of the CPI, most have rarely used the TCPI. It's a pity because the TCPI, when used in conjunction with the CPI, provides a powerful set of tools in the management of a single project, a program, or a full portfolio of projects.

EVM: The 10 Requirements

As a general rule, whenever a project manager makes the decision to employ EV in the management of a project, that choice ideally should be supported by management, the stakeholders at all levels. Stakeholders must want to know the full truth. The reason? EVM performance data can be available to everyone working the project: the functions, senior management, the paying customers, and essentially all parties who have a vested interest in the success of the project. As long as everyone has a rudimentary understanding of what the EVM data means, everyone connected to the project knows what everyone else is doing. Thus, it is imperative that there be a management buy-in whenever a project manager elects to employ EVM on a project.

The commitment to employing EVM requires both compliance with certain basic requirements and discipline on the part of everyone supporting the project. Based on our experience, we have listed the following 10 key requirements which must be met in order to successfully implement EVM. Some find these requirements overwhelming. See for yourself. These requirements are:

> *" ... the TCPI, when used in conjunction with the CPI, provides a powerful set of tools in the management of a single project, a program, or a full portfolio of projects."*

1. EVM requires that the project be fully understood, defined, and scoped to include 100 percent of the project effort. You need to know what constitutes 100 percent of the work in order to measure progress along the way.
2. EVM requires that the defined scope be *decomposed*. In other words, the scope is broken down into major management tasks that are selected as points of management control[2], then planned and scheduled down to the detailed work package level.
3. EVM requires that an integrated and measurable project baseline be authorized, relating the scope of work directly to an achievable budget, then locked into a specific timeframe for performance measurement. It's called bottom-up planning.
4. EVM requires that only authorized and budgeted work be accomplished. The effort being worked must be tightly controlled. Scope creep cannot be allowed. All changes must be managed, and not worked until specifically authorized by the project manager.
5. EVM requires that physical performance be measured (the EV) using previously defined schedule metrics.
6. EVM requires that the values earned be related to the PVs to reflect performance against the project baseline. EV less the PV represents a variance from the baseline plan.
7. EVM requires that the ACs being reported be consistent with the EV being measured to allow for an accurate portrayal of cost performance. The relationship of values earned to ACs reflects the true cost performance. EV less ACs provides cost performance.
8. EVM requires that forecasts be made periodically (weekly, monthly) as to how much time and money it will take to complete 100 percent of the project.
9. EVM requires that a full disclosure of actual results be made to all persons who have a vested interest in the project. All stakeholders will receive the same actual performance results. Only one set of books is allowed.
10. EVM requires that project management, in conjunction with management at all levels and customer stakeholders, decide on the appropriate actions to be taken to stay within the authorized project expectations.

These 10 requirements are needed to successfully implement EV on any project. In our opinion, these requirements

constitute nothing more than following fundamental project management best practices.

We will now discuss what we believe to be the most important EV indicators: the CPI reflecting completed performance, and the TCPI with a focus on the required future performance.

What Is a CPI, and How Is it Used?

The EVM CPI is a reflection of project cost efficiency. The CPI relates the physical work accomplished, expressed in its budgeted value, against the ACs incurred to accomplish the performed work. Budgets can be set with various monetary values, hours, deliverables, or anything else that can be measured. The issue: Is the project staying on target, underrunning, or perhaps overrunning costs? This concept is portrayed in Figure 1.

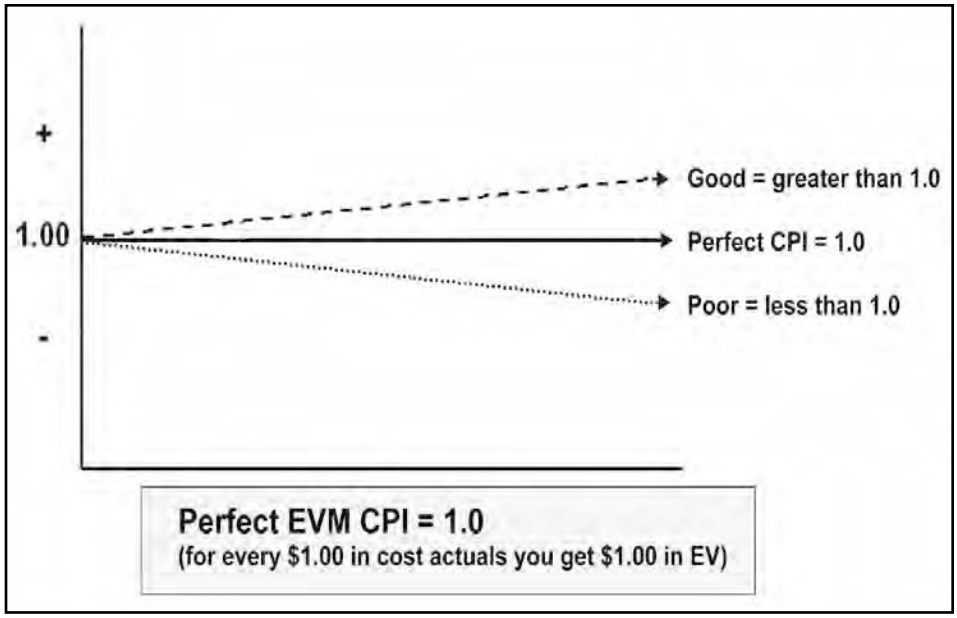


Figure 1: *Monitoring Earned Value Cost Performance*

Perfect cost performance would be defined as achieving a CPI of 1.0: For every dollar spent, we would get an EV equal to one dollar. Sometimes we do better, sometimes worse. This is a particularly critical metric to track because performance at less than 1.0 is a reflection of excessive costs spent against budget. Initial overruns are typically non-recoverable. Think about it: In order to recover an overrun, future work must be underrun. Rarely does this happen. The same conditions which may have caused the overrun in the first place are likely to occur again and again.

Sometimes the CPI will reflect values over 1.0, suggesting that an underrun of costs is occurring. Care must be taken when actuals reflect an underrun of costs to budget. Oftentimes, this condition is simply the result of costs which are lagging (slow to be recorded in the organizational cost ledger). For example, let's say you measure the EV and give full credit, but the related costs are not reflected in the cost ledger. The reason? Most of the project work may be performed by outside purchased labor (people who are not part of the internal labor system). Thus, there can be a time mismatch between the EV measured and the actual payment of the purchased labor invoices. The payment of invoices generally takes more time than the recording of labor.

Underruns of costs are rare. And, if artificially caused by lagging ACs, the positive results can hide or offset problems that need management attention. It takes organizational discipline to make sure that EV credits match the ACs.

Why is the CPI so important? Because past performance can be used to accurately determine requirements for final performance, in order to meet financial goals. The cumulative (from the beginning) CPI has been shown to stabilize from about the 20 percent completion point of project performance. Empirical scientific studies by the DoD on 155 actual contracts has shown that at the 20 percent point of project completion, the final projected results will only change by plus or minus 10 percent [1]. What a finding! What useful data.

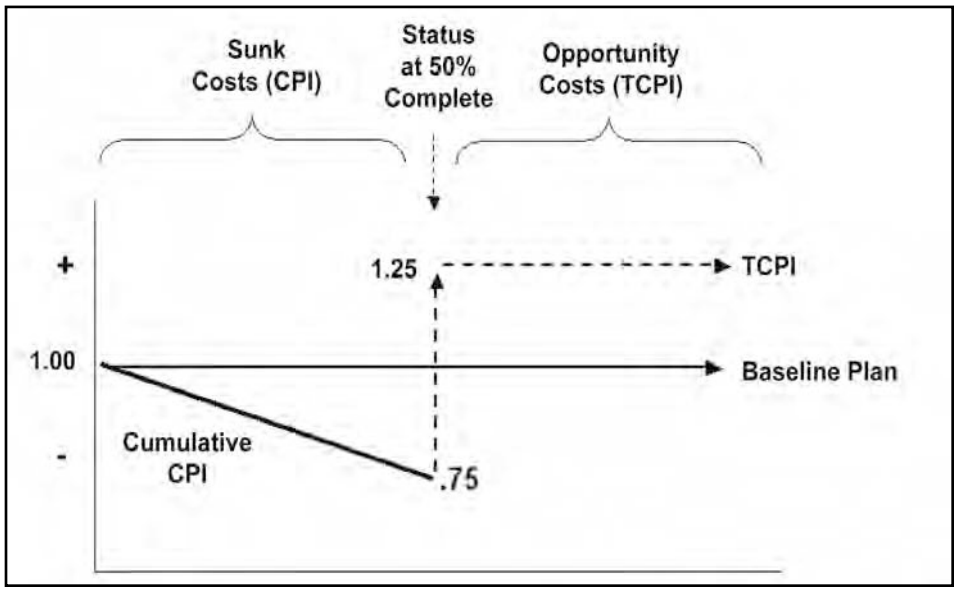
In practical terms, one can immediately take the total authorized budget (BAC), divide it by the cumulative CPI, and predict the total costs of a project with an accuracy of plus or minus 10 percent. If management doesn't like the final cost projection, then corrective action can be taken to change the forecasted results. Few project management techniques give a comparable early-warning signal. This formula, the BAC/Cumulative CPI = EAC, can be used on the total project, or any subproject, or with integrated project teams to predict final results on their work.

The CPI metric can be used to track periodic results (monthly, weekly, daily) or the cumulative position to see the long-term performance trends.

What Is a TCPI, and How Is it Used?

Whereas the CPI is an indicator of past cost performance, the TCPI has its

Figure 2: *The Relationship of Cumulative CPI vs. TCPI*



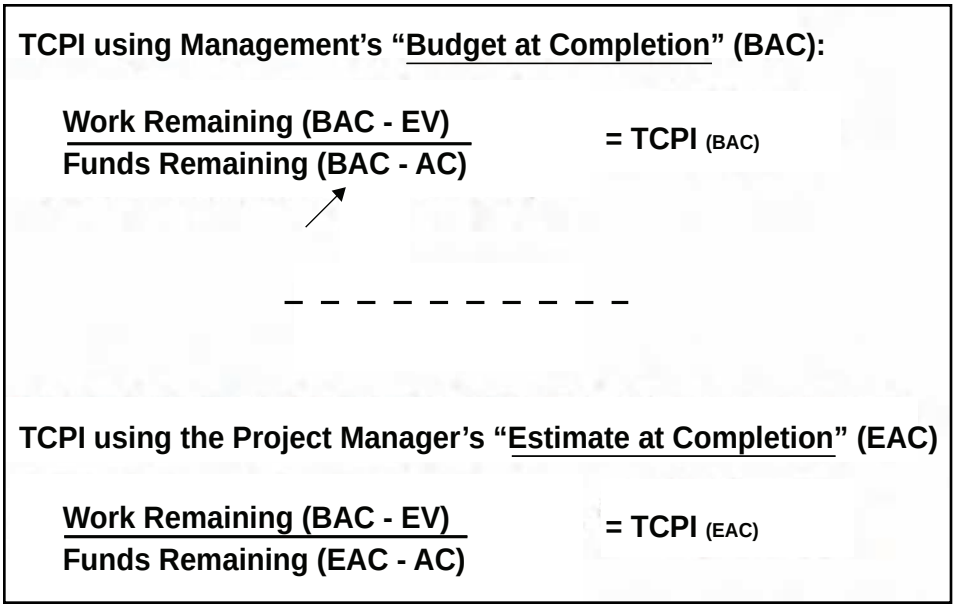


Figure 3: *Two TCPI Formulas*

focus on future performance. At issue: What will it take to meet the goals set by management? The TCPI works in conjunction with the CPI, and is conceptually illustrated in Figure 2 (see previous page).

The CPI can be thought of as sunk-costs; whatever the results, they cannot be altered. In the illustration shown, the cumulative CPI is at .75; for every dollar spent, only 75 cents of project work was earned. If the project is exactly 50 percent complete, one would need to accomplish $1.25 for every future dollar in order to stay within management's budget. Will this happen? At best, it is highly unlikely. Opportunities for improvements are illustrated by the use of the TCPI.

The formula for the TCPI is: The [Work Remaining] (defined as total Budget less the EV) divided by the [Funds Remaining]. Note that in Figure 3 there are two scenarios for Funds Remaining[3]. Funds remaining will focus initially on the authorized budget. Management will track performance against what it has authorized in the form of an official budget. However, once it becomes obvious that the budget is no longer achievable, management must determine how much money it will cost to complete this job (called the EAC). The project then stops work and makes a new forecast of what is needed to finish the job.

Preparing a new EAC forecast can get emotional. Unrealistic optimism sometimes takes over, at the expense of realism. It is not uncommon for projects, when making a new EAC forecast, to assume that everything will suddenly go right, and that all project risks are behind them. Thus, an initial EAC may be unrealistic or unachievable. Piecemeal EACs are often the norm, where the EAC projection goes up each month as actual performance is known.

Using Figure 2 as an example, would an EAC requiring a future TCPI of 1.25 or 1.10 be achievable? Probably not. More likely, a TCPI of 1.0 or .90 would be reasonable. But it is painful to admit the full value of an EAC, having just acknowledged that the BAC is no longer valid.

Conclusion

Employing the EVM technique can present a project with data not available with any other management tool. And while each metric can be useful, we believe that the two metrics described are particularly useful in the management of any project, or program, or a portfolio of projects.

Reference

1. Christensen, David S. "Using Performance Indices to Evaluate the Estimate at Completion." The Journal of Cost Analysis. Spring 1994: 19.

Notes

1. The terms are: Planned Value, Earned Value, Actual Cost, Schedule Variance, Schedule Performance Index, Cost Variance, Cost Performance Index, Budget at Completion, Estimate at Completion, and To-Complete Performance Index. All terms used in this article are consistent with the "Guide to the Project Management Body of Knowledge," 4th edition, published in December 2008 by the PMI.
2. The points of management control are sometimes called project teams, subprojects, or control account plans, depending on the organization.
3. Figures used in this article are inspired by "Earned Value Project Management," 3rd edition, Quentin W. Fleming and Joel M. Koppelman, PMI, 2005.

About the Authors

Quentin W. Fleming is a management consultant specializing in EV. He has been a consultant to the staff at Primavera Systems, Inc. since 1993. Fleming was on the core team that updated the PMI's "Guide to the Project Management Body of Knowledge," released in December 2008. He co-authored the book "Earned Value Project Management," published by the PMI, with the latest edition released in 2005.

14001 Howland WY
Tustin, CA 92780
Phone: (714) 731-0304
Fax: (714) 731-0304
E-mail: quentinf@quentinf.com

Joel M. Koppelman is the co-founder and CEO of Primavera Systems, Inc. He co-authored the book "Earned Value Project Management," published by the PMI, with the latest edition released in 2005.

Primavera Systems, Inc.
Three Bala Plaza West
Bala Cynwyd, PA 19004
Phone: (610) 667-8600

Certifications Help Organizations and Clients

George Jackelen
Software Consultants, Inc.

As part of the United States government's request for proposal (RFP) process to acquire products and services, more emphasis is currently being placed on the past performance/experience proposal section. This article addresses another area the government (and other potential clients) should examine, especially for potential bidders with limited experience: organizational certification by certified, independent assessors based on internationally and nationally recognized standards and methodologies[1].

In a *Washington Technology* article [1], Michael Hardy describes how certifications help contractors to compete and thrive. This article expands this theme by describing how contractor certifications can help organizations improve, help clients choose contractors, and how certifications can be used to provide better services and products.

My definition of certification is:

> Being accredited by an external independent group certified by a standard's (to include methodologies) owner to evaluate organizations and to provide objective evidence to a nationally/internationally recognized group (for example, the American National Standards Institute – American Society for Quality National Accreditation Board) to issue formal certificates of approval.

Internal accreditation is not addressed because, in my opinion, they rarely provide independence to identify and document the existence of objective evidence and artifacts; indeed, I have witnessed data manipulation to provide an organization with the desired results. I do accept the importance of internal audits for the purpose of gap analysis to determine what is missing to fulfill compliance requirements.

Capacity and Experience

Before going into a discussion about certifications, I want to discuss the terms *capacity* and *experience*, which some people consider to be the same.

An organization's capacity—defined as "the potential or suitability for holding, storing, or accommodating" [2]—is not a reliable evaluation tool. Capacity does not always provide objective evidence that an organization can actually provide this capacity or really knows how to satisfy the requirements. Thus, an organization can have a capacity to do something without ever having experience doing that thing. Also, a stated capacity may only be due to one employee's capacity (who may leave the organization or may not work on the contract) or education (e.g., a person took a course on the topic, but has no application experience); rather than having several people with the capacity and/or having organizational documented and implemented procedures on how to provide a stated capacity. Thus, there may be no evidence to show a capacity was ever provided successfully by an organization.

"I have seen the distinction between capacity and experience applied to RFPs when a client wants organization/team experiences (reality) rather than capabilities (theory)."

An organization's experience—defined as "the act of living through an event or events" [3]—is more valuable to a client. Thus, a capacity is not the same as experience, nor should capacity have as much weight in an evaluation as experience. For example, advertisements say my car has the capacity to provide 30 miles per gallon (mpg); but, in the real world, I have no experience where my car had an actual performance measurement of 30 mpg or greater.

Thus, experience is better than capacity to determine if an organization can support a client. This is especially true if the client contacts the referenced clients, identified in the experience part of a proposal, for their view of how well the organization performed and/or implemented their processes and developed the needed product or service. This step is similar to verifying a future employee's references, experience, and education.

I have seen the distinction between capacity and experience applied to RFPs when a client wants organization/team experiences (reality) rather than capabilities (theory)[2]. I recognize that experience may not be a true reflection of an organization's present and future environment. Also, some organizations are too new or too small to have the needed experience. In these situations, an organization may not bid or a client may not have high confidence that an organization can deliver what a client expects.

A possible solution to this dilemma is for clients to examine an organization's certifications. I am ignoring employee certification since people can leave an organization and employee certifications do not show that an organization has implemented the principles of these certifications. However, I have seen RFPs requiring the proposed people who will work a contract to have specific certifications (e.g., related to information or computer security).

Independent Certifications

I recommend clients require a copy of each organizational certificate related to the RFP. Independent certifications (e.g., the International Organization for Standardization [ISO]) can help organizations and clients reduce the risk of having a lack of experience by showing clients the organization has a certified set of processes in place. Besides having processes in place, certifications are based on independently observed objective evidence showing that the processes are implemented as stated.

Why should clients believe that certification is a bridge between an organization's capacity and its lack of client-required experience? Since receiving an organizational certificate is not cheap and cannot normally be obtained in a few months, clients should recognize an organization for its willingness to expand resources so they can prove their processes are established and maintained, and are actually implemented. At the same time

(prior to being certified), auditors/certifiers spend a lot of time looking for objective evidence that organizations comply with the given standards and certification requirements. For a client, this means organizations must not only have processes in place, but must also prove these processes are implemented as stated.

Another organizational factor—an important cost-benefit determination for an organization—is deciding what part of the organization is to be certified (i.e., the whole organization or an organizational subset). Can an organization afford to wait for a payback that may not appear for months after certification? For a client, certification may be with an organizational subset that is not proposed to participate on a contract or is only providing minor contract support.

Therefore, organizations need to make a decision about their need for certifications, what certifications they want to achieve, what part of the organization to certify, and their willingness to pay the cost. Organizations must also be aware that the cost to be certified does not end with certification. For ISO and the Software Engineering Institute (SEI), for instance, achieving certification is not a *be all and end all*. ISO and SEI require periodic recertification to assure the certification standards and organizational processes are maintained and the processes are implemented. To an organization, achieving certification and recertification may be a key to future contracts, especially for RFPs requiring particular certificates.

For clients, this means certification is not a lifelong *license to brag* based on a one-time evaluation of an organization. As a result, clients need to know when an organization was last certified and the certificate's duration.

What Certifications Will Meet an Organization's Needs?

Given what I've just explained, what certificates should an organization apply for and what certificates should a client look for? The answer depends on an organization's goals and objectives—and what a client is looking for to ensure the right organization is picked to execute a contract[3].

Table 1 provides examples of four major international standards that provide recognized certifications, and examples of how these standards relate. The first qualification (ISO 27000) should be strongly considered by clients and organizations since sensitive data security (e.g., payroll or personnel records) is critical to most clients and organizations. In addition, this certification is important for its guidance on providing physical and procedural protection of data, physical equipment, people, and the operational environment.

The second qualification (ISO 9001) is arguably *the standard that set the standard* for the other qualifications. The third qualification (ISO 20000) is not known by many organizations, but it expands ISO 9001 by addressing IT's involvement with business needs and strategy. Several ISO 20000 requirements relate to ISO 27000 and ISO 9001. As a result, achieving ISO 20000 certification helps an organization to also achieve ISO 9001 and ISO 27000 certification. ISO 20000 certification can also help organizations with CMMI® appraisals.

> *" ... organizations need to make a decision about their need for certifications, what certifications they want to achieve, what part of the organization to certify, and their willingness to pay the cost."*

Table 1 also shows some of the similarities between the three international standards and an internationally accepted methodology/model (CMMI) to improve quality.

Certifications

Due to similarities with certification, this article addresses only the following standards because they are internationally well-known in assisting organizations to improve their quality, efficiency, and effectiveness (other standards could be added):

- **ISO 27000:2005, IT – Security Techniques – Information Security Management.** Provides a model for establishing, implementing, operating, monitoring, reviewing, maintaining, and improving an Information Security Management System (ISMS).
- **ISO 9001:2000, Quality Management Systems – Requirements.** Intended for use in any organization which designs, develops, manufactures, installs, and/or services any product or provides any form of service. It identifies the requirements an organization needs to fulfill to achieve customer satisfaction through consistent products and services meeting client expectations. It includes a need for continual (i.e., planned) improvement of a Quality Management System.
- **ISO 20000:2005, IT – Service Management.** Promotes the adoption of an integrated process approach to effectively deliver management services to meet business and client requirements. Its process improvement can be managed through the CMMI approach.
- **CMMI.** A methodology enabling organizations to identify the maturity level achieved by their processes, and to design and implement a continuous improvement plan to raise their process maturity level to one appropriate for their business objectives.

Using the Standards and Methodology

For this article, these standards relate to organizational-level quality (e.g., what is best for an organization or its sub-organizations), not just lifecycle processes (e.g., what is required to perform requirements analysis, design, or testing). For instance, lifecycle processes normally minimize top management's business goals and objectives whereas organizational-level requirements (the three mentioned ISO standards) emphasize business needs, goals, and objectives. In my opinion, CMMI ties together organizational-level and lifecycle processes.

Organizational requirements recognize the need for owners and key decision makers to decide if requirements are cost-effective, an organizational need, etc. For example, people normally recognize the need for alternate backup sites to protect an organization from collapse due to a disaster at a key organization location. However, at the organizational level, management may determine having one or more backup sites is too expensive since clients are unwilling to share in the cost, or the organization's business base is too diverse in functionality and/or geographic location to have back-up sites. Thus, an organization must formally identify the risks it is willing to accept even when attempting to be certified.

The mentioned standards allow an

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Items	ISO 27000:2005	ISO 9001:2000	ISO 20000:2005	CMMI
Planning	1 Scope 1.2 Application	1 Scope 1.2 Application		Process Area (PA) Project Planning
Quality Management	4 Information Security Management System 4.2 Establishing and Managing the ISMS 4.2.1 Establish the ISMS 4.2.2 Implement and Operate the ISMS 4.2.3 Monitor and Review the ISMS 4.2.4 Maintain and Improve the ISMS	4 Quality Management System 8.2.3 Monitoring and Measurement of Processes 8.2.4 Monitoring and Measurement of Product	5 Planning and Implementing New or Changed Services	PA – Requirements Development PA – Integrated Project Management Specific Practices 3.1 – 3.5 PA – Project Monitoring and Control (PMC) General Practice (GP) 2.8 Monitor and Control the Process PA – Measurement and Analysis (MA) GP 3.1 Establish a Defined Process GP 3.2 Collect Improvement Information
Quality Plan, and Maintenance of Documents and Records	4.3 Documentation Requirements 4.3.2 Control of Documents 4.3.3 Control of Records	4.2 Documentation Requirements 4.2.2 Quality Manual 4.2.3 Control of Documents 4.2.4 Control of Records	3.2 Documentation 4.1 Planning Service Management (Plan)	PA – Process and Product Quality Assurance (PPQA) PA – Configuration Management GP 2.6 Manage Configurations
Audits	6 Internal ISMS Audits	8.2.2 Internal Audit		PA – PPQA
Process Improvement	8 ISMS Improvement 8.1 Continual Improvement	8.5 Improvement 8.5.1 Continual Improvement	4.4 Continual Improvement	PA – MA PA – PMC GP 2.2 Plan the Process
Reviews	7 Management Review of the ISMS 7.2 Review Input 7.3 Review Output	5.6 Management Review 5.6.2 Review Input 5.6.3 Review Output	4.3 Monitoring, Measuring, and Reviewing	PA – Decision Analysis and Resolution GP 2.9 – Objectively Evaluate Adherence GP 2.10 – Review Status with Higher Level Management

Table 1: *Sample Relationship Showing Similarities Between the Four Standards*

organization to tailor the implementation of the standards to match how an organization operates. For instance, ISO 9001 allows clauses to be deleted if an organization does not implement a clause (e.g., clause 7.3, Design and Development, if an organization does not design or develop products).

But how does an organization receive authorized certification? Is this process of any benefit to potential clients?

The Process to Receive Certification

Each standards development group has its own certification process and there are many Internet sites discussing the processes to receive independent certification. Some requirements are the existence of objective evaluations and a history (e.g., at least three months) of artifacts (proof) to show organizational processes are implemented. Another requirement is for the organizational processes to comply with an authorized standard. Most organizations should be able to ensure this requirement is being satisfied through an objective gap analysis (internal audit) of their processes versus a given standard. Many organizations—even if they have effective, efficient processes in place—find they lack objective artifacts showing a continuous and objective use of the processes stated within a given standard.

Conclusion

The identified standards have publicly assessable databases with information about what organizations are currently certified. However, clients must be aware that status posting may take weeks to be stored into a database or for an organization to receive a formal certificate. Because of this, clients must determine the cut-off date for an active certificate (e.g., the certificate must be valid on the date proposals are due, so many calendar days after a proposal is due, or at the time of the contract award). Another option, if an organization's certificate has yet to be posted, is for a client to allow an organization to provide a copy of its certification packet to indicate the certification results. In this case, the RFP needs to state that if an official certificate is being processed that the entire certification packet must be included in the proposal so a client can identify the auditor's recommendation for approval. In this situation, I recommend that the RFP also states that an official certificate must be provided upon contract award.

Whether a database or a certificate copy is used, clients need to be aware that some organizations exaggerate the certification results. Commonly, an organization's subset may be certified, but an organization indicates the certification is at the organizational level covering all organizational subsets. To overcome this problem,

Coming Events

February 2-4

Soldier Technology U.S. 2009
Arlington, VA
www.wbr.co.uk/soldiertechnologyusa/

February 3-5

3rd Annual Lean and Six Sigma for Process Excellence in IT and Software Development Conference
San Francisco, CA
www.wcbf.com/quality/5089/

February 8-11

16th Annual Network and Distributed System Security Symposium
San Diego, CA
www.isoc.org/ndss09/

February 10-12

USAF Test and Evaluations Days 2009
Albuquerque, NM
www.aiaa.org/content.cfm?pageid=230&lumeetingid=2104

February 25-26

AFCEA Homeland Security Conference
Washington, D.C.
www.afcea.org/events/homeland/landing.asp

April 20-23

21st Annual Systems and Software Technology Conference
Salt Lake City, UT
www.sstc-online.org

Coming Events: **Please submit coming events that are of interest to our readers at least 90 days before registration. E-mail announcements to: nicole.kentta@hill.af.mil.**

certificates and certification databases clearly state what part of an organization is certified. As a result, clients need to go beyond just accepting the word of organizations. Clients need organizations to provide objective evidence (e.g., copy the certificate) or have the client verify an organization's certification statement based on certification databases.

Is this proof of certification worth it? Clients can use certifications to establish the chances that an organization or subset can deliver the needed product or services on time, within cost, and at the needed quality level. When an organization provides proof of performance and a copy of its certificate, this provides a client with a degree of confidence that the organization can satisfy the client's needs.

However, an important reminder for clients is that the existence of a certificate does not mean an organization will actually use what is said within a certificate. As a result, clients need to contractually receive the plans, processes, steps, etc., used to receive an organization's certificate(s), and organizations must receive client approval for modifications to these plans, etc.

Having performed independent verification and validation (IV&V) for more than 12 years, I have seen organizations win contracts based in part on certifications (e.g., having a CMMI Level 5), but they do not implement these features during a contract. In this situation, I blame the client for not verifying the implementation of what was promised or clearly implied in the proposal. For example, I have seen a major, well-known organization's CMMI Level 5 subset (which was stated in their proposal and contract) not be penalized for failure to use promised standards. Thus, the client promoted the importance of cost and schedule over quality.

Therefore, a client can use an organizational certificate to show an organization has implemented documented processes (that were based on known standards). However, it is up to the client to sometimes require an organization to use the certified processes for a given contract.

Also, certification does not guarantee successful implementation of quality processes or delivery of quality products or services. What certifications do provide is objective evidence that a certified independent group has examined artifacts showing that an organization has implemented processes to satisfy stated standards.◆

References

1. Hardy, Michael. "Get your ducks in a row." Washington Technology. Vol. 23, No. 2. 11 Feb. 2008 <www.washingtontechnology.com/print/23_02/32228-1.html>.
2. "Capacity." Merriam-Webster Online Dictionary. Merriam-Webster Online. 2008 <www.merriam-webster.com/dictionary/capacity>.
3. "Experience." Webster's New World Dictionary.

Notes

1. Since the author is not a government employee, he is not providing guidance currently used by the government to assist in making better selections based on the RFP process.
2. The U.S. government uses RFPs to ask organizations to provide a proposal addressing the issues provided in the model contract and statement of work (SOW). The resulting proposals determine what organization(s) wins a contract to provide the SOW-stated needs. Within the RFP, the government identifies the evaluation criteria (e.g., understanding of the problem, past performance, technical and/or management approach, and cost) and the priority or weight of each criterion.
3. The standards I cite do not provide detailed requirements (e.g., what level of software testing is required). They are at a high level to address what organizations need to implement to ensure quality processes, products, or services, without disrupting an organization's goals, objectives, and level of acceptable risks.

About the Author

George Jackelen is currently working with Software Consultants, Inc. as a principal consultant. Since 1996, he has provided IV&V support to various federal agencies and in Colorado and California. Prior to that, Jackelen spent 10 years in quality assurance and 20 years in the USAF in various computer jobs. He also assisted the ISO, the IEEE, and the Project Management Institute in developing standards.

Software Consultants, Inc.
4601 President's DR
STE 240
Lanham, MD 20706
E-mail: georgej@scigrp.com

Using Software Quality Methods to Reduce Cost and Prevent Defects

Rick Spiewak
The MITRE Corporation

Karen McRitchie
Galorath Incorporated

Everyone knows that it's better to "do it right the first time." But in organizations, this requires the ability to predict outcomes of their established "best practices" as well as the ability to justify costs when it comes to applying what may be new approaches. This is just as true in software development as it is in any other business practice. This article will survey some of these best practices and present a method for evaluating the costs and benefits of applying them.

Software can be considered a product whose production is fundamentally similar to other products. Improving the quality of software can be approached using the same basic principles espoused by quality pioneers such as W. Edwards Deming, Philip B. Crosby, and Harold F. Dodge. These principles can form a practical framework for ensuring that appropriate requirements are set for software development projects. By connecting established software engineering practices to the objective of defect prevention, we can apply the principles of quality management to software development. Using modeling techniques, it is possible to predict the potential cost savings and defect reduction expected.

Quality management is a well-established discipline with historic roots in manufacturing industries. W. Edwards Deming [1], Philip B. Crosby [2], and others have written and taught extensively in the field. The classical approach to quality management can be summarized in these simple steps:

1. Analyze product defects to determine root causes.
2. Modify processes to address and remove root causes of defects.
3. Fix defects using improved processes.

By following this approach, we can realize the goal of improving product quality by removing the causes of defects. As Crosby put it: "Quality is free. It's not a gift, but it is free. What costs money are the non-quality things—all the actions that involve not doing jobs right the first time" [2].

Identifying Best Practices

While the classical approach to quality management (as taught by Crosby and others) would suggest that each organization should start fresh in identifying and fixing process defects in order to improve product quality, experience suggests otherwise. The famous mathematician and computer scientist Richard Hamming once asked, "How do I obey Newton's rule? He said, 'If I have seen further than others, it is because I've stood on the shoulders of giants.' These days we stand on each other's feet" [3].

If we want to profit from the work of pioneers in the field of software quality, we owe it to ourselves and them to stand on their shoulders. This means that we should be willing to adopt proven best practices without necessarily requiring that their value be proven first in our specific development environment. We will try to identify some of these best practices and focus our attention on them here.

Narrowing Our Focus

There is no doubt that the quality of software is heavily influenced by proper attention to every phase of development, from conceptual design through requirements definition, architecture, detailed design, construction, testing, documentation, training, deployment, and sustainment. However, for the purposes of this article, we will focus on what Steve McConnell refers to as the *software construction* [4] phase of software development.

Best Practices in Software Construction

This article will treat four areas of best practices in software construction:

- Uniform coding standards.
- Automated Unit Testing (AUT).
- Root cause analysis.
- Code reuse.

These areas, in turn, can be linked to the four software construction fundamentals cited in the IEEE Computer Society's "Guide to the Software Engineering Body of Knowledge" [5]. It stated that the fundamentals of software construction include:

- Minimizing complexity.
- Anticipating change.
- Constructing for verification.
- Standards in construction.

Proper attention to these areas will lead to improved quality in the software we create, while moving closer to Crosby's idea that quality can, in fact, be *free*.

Uniform Coding Standards

Coding standards incorporate experience and best practices at a detailed level into the software construction process. Typically, these include the seemingly trivial, such as spelling, use of names, and upper/lower case; the moderate, such as the code matching the in-line documentation; and the critical, such as proper management and disposition of objects, exception handling, completeness of branch tests, and so forth.

The use of uniform standards provides a wide range of benefits:

- **Readability.** Any programmers writing to the same standards will be better able to read, critique, or even take over software written by others. This saves time and avoids misunderstandings in areas including peer reviews, updates and maintenance, and reassignments.
- **Support by tools.** Static analysis tools are available for contemporary programming languages and environments, which incorporate the ability to check for adherence to coding standards and best practices in writing code. By adopting the standards supported by these tools, we obtain the advantage of increased automated tool use, one of the metrics used in the System Evaluation and Estimation of Resources – Software Estimating Model (SEER-SEM), as referenced in the forthcoming Using the Model section.
- **Peer review benefits.** The peer review process is enhanced by the adherence to uniform coding standards. Code is more accessible to potential reviewers and less time is wasted adapting to differing approaches. The review can focus on actual and potential defects and their causes.

In addition to checking for adherence to standards, peer review leads to the sharing of ideas and improved coding techniques. Inspection by the developer prior to review may contribute to defect prevention as well.

Government audit of the peer review

process is enabled by coding standards. Software should be randomly reviewed on behalf of the customer in order to ensure that a uniform approach is being followed.

AUT

Developers have long been responsible for unit testing their code. This involves testing the smallest possible part of a program to ensure correct operation. Techniques for unit testing include the use of a debugger to step through a routine, following a script which exercises the desired functions, and the use of a test *harness* or *framework* to execute tests automatically. The last of these techniques is generally referred to as AUT.

While strategies for analyzing unit test requirements include Dr. Thomas Radi's TestGen for Ada [6] from 1989, the best-known lineage of modern AUT dates from SUnit for Smalltalk [7] in 1994. This was followed in 1999 by JUnit (for Java). Because of this heritage, and the fact that the basic structure of these test harnesses has been carried forward into multiple environments, AUT is often represented by the *XUnit* family of test harnesses, including JUnit and NUnit (for Microsoft.NET). Note that the *automation* in this family of test harnesses is in the *execution* of tests. There are other tools available that will help to create at least a skeleton of the tests themselves. It is up to the developer to ensure, by the use of tools and inspection, that there is sufficient coverage of input values and paths through the code to provide the desired thoroughness.

There is a positive impact on design when automated unit tests are implemented from the beginning. In order to prepare for AUT, code must be designed to be tested. Construction techniques such as *dependency injection* or *dependency lookup* [8] help to reduce coupling between software modules, enhance modularity, and aid in testability. For a more complete discussion of unit testing patterns and techniques, see [8].

In addition to aiding in the initial assurance of correct operation, automated unit tests serve as regression tests for existing methods and routines in the course of development by continuing to test previously working code each time they are run. During maintenance and enhancement, this regression testing helps to prevent the introduction of new errors into existing code.

When used together with requirements for code coverage, automated unit tests can be used to both prevent regression errors and set minimum standards of correct operation. There are tools available which will work in conjunction with unit test tools to show how much of the code under test is being executed in a particular scenario.

One well-known approach to AUT, Test Driven Development [9], extends the testing model so that tests are written first, then code is added to pass the tests. This has the additional benefit of focusing development on the requirements and discouraging what has been called *feature creep*: adding features or capabilities while programming.

The "Haves" and the "Have-Nots"

What we found, in an informal survey of users of AUT, is that development organizations which use it do not have detailed cost comparisons available. In general, once they started using it, they just never went back to traditional manual methods, nor have they deemed it worthwhile to conduct comparative studies. Those who have not yet adopted these tools have sometimes not done so because of the perception that it will cost more. We will attempt to show that, over the course of development, this perception is false.

"When used together with requirements for code coverage, automated unit tests can be used to both prevent regression errors and set minimum standards of correct operation."

Root Cause Analysis

Root cause analysis is the most fundamental technique of quality management, and is a CMMI Level 5 practice area. It is important to use this technique, however, regardless of the CMMI level. Fixing defects in a product without addressing the cause is known in classic manufacturing environments as *rework*. It is no different in software development, where we call it *fixing bugs*. Without addressing root causes, there is no reason to believe that simply reworking software defects will improve the quality of the overall result, since the same (potentially flawed) processes are used to make the changes as were used originally to write the code.

Accepted techniques for analyzing root causes include the *5 whys* method and Kepner-Tregoe Problem Analysis method [10]. The former method was originally developed at Toyota Motor Corporation and is deceptively simple: When analyzing a defect or failure, start by asking *why?*, and continue asking this for each answer until a satisfactory root cause is reached. The number 5 is simply a guideline in this case.

Kepner-Tregoe's Problem Analysis takes a different approach, asking (with regard to a defect or failure): *What? Where? When?* and *To What Extent?* These questions are addressed in terms of what the problem is, what it could be (but is not), and what changes and differences are associated with the occurrence. These are then analyzed for determining possible root causes.

Analyzing and addressing root causes is essential to improving the development process. However, in order to preserve and then later analyze the knowledge gained by this approach, it is necessary to classify root causes.

Classification: Root Cause Taxonomy

A variety of schemes have been proposed and used for classification of root causes. These include IEEE Standard 1044 and IBM's Orthogonal Defect Classification [11]. However, these do not lend themselves well to automated analysis.

Boris Beizer [12] provided a simple approach to root cause classification. The Beizer Taxonomy yields a 4-digit number. Based on an open-ended hierarchical classification scheme, it can be extended without changing the original categories.

One of the advantages of this approach is that it is amenable to analysis using database query tools, Pareto diagrams, and statistical techniques for extracting patterns from data. Consistent use of this taxonomy can provide an enterprise with insights into areas for process improvement that might not be readily apparent otherwise. The enterprise, for example, may be a customer for software which is written by a variety of development organizations.

Table 1 shows the top level categories of the Beizer Taxonomy.

Software Reuse

Through the use of uniform coding standards and designing software to be readily tested by automated unit tests, there is an increased likelihood that software devel-

oped for one project or program can be reused by another. Good documentation and modular design are also needed to make software reusable.

Additional value can be added when reliable open-source or other freely available software with a large body of users can be applied to a project. Depending on the development environment and language(s) involved, this may mean looking at open-source projects or libraries such as the Microsoft Enterprise Library (for the .NET Framework).

Many of these sources meet the other previously discussed criteria, such as using well-established coding standards and including automated unit tests. Available software which does not meet these criteria has an implicit cost in adopting it for reuse: Bringing the software up to the same standards used during specific development for the project may be required.

Cost/Benefit Analysis

In order to analyze the benefits of introducing techniques aimed at improving software quality, we need to find a way to predict the results. This is accomplished through the use of modeling and comparing the predicted outcome of the development effort under varying conditions and practices.

Modeling the Cost of Improving Quality

Crosby defines the *cost of quality* as "… the expense of non-conformance—the cost of doing things wrong" [2]. This can be added up after the fact as the cost of rework and scrapping the work (in the case of software, the cost of fixing defects in the code). But, suppose we want to predict ahead of time what the benefits might be of applying some of the fundamental best practices previously described to a development project? Take, for example, the problem of the benefits of AUT and static analysis.

Costs and Benefits of AUT

One of the most intractable problems in considering the introduction of best practices into the software construction phase has been justifying the cost. If you attempt to look at the value of AUT in isolation, this fundamental problem presents itself: Most sources agree that to test *n* lines of source code requires at least *n* to *n + 25* percent additional lines of code [13]. If you apply this to a traditional estimating approach which multiplies source lines of code (SLOC) by hours or dollars, it will appear that the use of this technique will add significant cost to the project. If this were so, then the apparent fact that organizations using this technique are so thoroughly committed to it would seem to be contradictory.

Fortunately, there is a more comprehensive approach. The cost modeling software which is in use by the AF Electronic Systems Center at Hanscom AFB takes in to account a number of factors in addition to SLOC. These include the use of automated tools, the degree of testing, and the extent of quality assurance. This allows us to see past the SLOC issue, and estimate the savings which are possible by the use of these techniques.

Using the Model

The commercially available SEER for Software application is a comprehensive software project estimation system. SEER-SEM is the core estimation capability originally based on the effort and schedule relationships developed by Dr. Randall Jensen [14]. The SEER-SEM product comes with a comprehensive set of knowledge bases which offer default parameter values that target complexity and productivity factors for a wide variety of project types. These knowledge bases are developed and tested by analyzing thousands of projects. Initial inputs to a SEER-SEM estimate include a description of the platform, application type, reuse scenario, development methods, and development standards. Detailed inputs include several ways to enter software project size as well as several productivity-related parameters that help describe the people developing the software, the methods and tools used, the customer-driven requirements and constraints, and the system being developed. This allows the user to do *what-if?* analysis based on a variety of development strategies using various parameters related to the size of a project, its difficulty, the experience of the developers, and the tools and techniques used.

The use of a cost modeling tool to do *what-if?* studies serves as a means to simulate different scenarios. Ideally, it can provide an objective assessment of how cost, schedule, and quality might change as project assumptions change. In using SEER-SEM, you can evaluate the impacts of project assumptions to the whole project, not just the construction phase that is most directly impacted by AUT and static analysis tools.

From the perspective of cost modeling, AUT, along with tools that check source code for syntax or security errors, fall into the general category of *automated tool use*. According to the SEER-SEM model [15], increasing the use of automated tools actually decreases (rather than increases) the cost of developing software. In addition, it reduces the number of defects expected to be produced by the process.

Top-level categories:
- 0xxx Planning
- 1xxx Requirements and Features
- 2xxx Functionality as Implemented
- 3xxx Structural Bugs
- 4xxx Data
- 5xxx Implementation
- 6xxx Integration
- 7xxx Real-Time and Operating System
- 8xxx Test Definition or Execution Bugs
- 9xxx Other

Table 1: *Top-Level Categories of the Beizer Taxonomy*

In one example, changing the model parameter *Automated Tool Use* from Nominal to High, resulted in a projected decrease in effort of 9 percent, accompanied by a decrease of 13 percent in predicted defects. This shows that, contrary to a cursory estimate, doing the extra work to develop automated unit tests (along with other automated tool use) can be expected to reduce the overall effort involved in software development. While this result appears interesting, it is important to understand that changing a single parameter to study the cost and quality trade-off of AUT can be viewed as overly simplistic. Fortunately, there are other dimensions to this scenario that can be evaluated using a cost modeling tool.

It is fair to say that introducing automated tool use into a development organization will not produce instant benefits. Fortunately, the cost modeling tools allow for a more nuanced look at this *what-if?* scenario. In addition to looking at the impact of automated tool use improvement, we can consider experience factors and the potential for added volatility.

As an example, we will examine a project with three major applications and two vendor-supplied applications. The project is of moderate criticality in terms of the overall specification, quality assurance, and test levels required. There are three cases examined:

- **Baseline:** Assumes no AUT, which notionally represents the organization *as-is*. The team has nominal experience with the development environment, tools, and practices.
- **Introducing AUT:** Takes the baseline scenario with the introduction of

	Baseline	Introducing AUT	Difference	AUT + Experience	Difference
Schedule Months	17.09	17.41	2%	16.43	-4%
Effort Months	157	166	6%	139	-11%
Hours	23,881	25,250	6%	21,181	-11%
Base Year Cost	$2,733,755	$2,890,449	6%	$2,424,699	-11%
Defect Prediction	84	81	-4%	68	-19%

Table 2: *Cost Model Trades*

AUT. This will result in a small increase of the automated tool use parameter as well as the modern development practices. However, since the use of these tools is new to the organization and teams, there is a decrease in the overall development environment experience. Also, introduction of new tools may inject some volatility into the system. This is because the team may need to tweak the process to accommodate the tools being used. For example, they may need to upgrade to the latest service packs for their operating system or development environment in order to integrate the unit test tools effectively.

- **Introducing AUT and Added Experience:** Similar to the previous, but with the caveat that the team has had some training in the use of the AUT tools and has established the methods used as *routine*. This training may be done in a traditional classroom or *boot camp* environment, or it could be on-the-job training. In either case, the assumption here is that the team has gained some experience in using the AUT tools and the process is well integrated into their overall development process.

The results of these three runs are shown in Table 2.

Results include the estimated schedule months or duration and the estimated effort expressed as effort months, hours, and cost. The last row in the table is the estimated number of delivered defects. The defect estimate in SEER-SEM takes into account the project size, programming language used, as well as many of the productivity factors used to estimate effort (e.g., requirements definition formality, specification level, test level, and others).

The results of this analysis demonstrate that there is an initial hit to overall productivity when introducing new tools and methods. However, this impact is not a long-term change, but rather a short-term setback that can be overcome by training or general experience. It is worth noting that even without the benefit of experience, the number of defects went down with the introduction of AUT.

By adding the dimension of defect prediction into the cost-modeling method, you can quantify the impact of changes in tools, methods, and staff capabilities used on a project, not just in terms of investment or savings, but also in terms of improved quality. Software managers need to be able to justify investments in new tools and technologies, but using claims by tool vendors can be misleading. Investment in quality improvements should be analyzed, not just for the general effects, but for their effects on specific projects. It is important to not just look at the benefit of the coding effort (as many tool vendors will provide), but to the overall benefit of the project.

In addition to the end result, visibility into the defect profile over the development period is available as part of this cost model. The *defect prediction* is considered to be defects delivered at the end of development. However, projects find and remove many more defects during development. Every project has a *defect potential* that represents the opportunity for defects to occur during development and beyond. The defect potential is based on size, complexity, and other factors. In general, most of the potential defects are found and removed through the development process. However, not all are removed, leaving delivered defects. The percentage of defects removed during development is called the *defect removal efficiency*. This is calculated as the total defects removed divided by total defect potential. Higher defect removal efficiencies are typically associated with the use of more rigorous or formalized software development methods.

The detail behind the quality metrics in this analysis, shown in Table 3, is provided by the cost model. When introducing AUT, you see a small increase in the defect removal efficiency. However, this increase is offset by an increase in the overall defect potential that results in an increased number of hours spent removing each defect. However, when you couple AUT with the requisite experience, the increase in defect removal efficiency is boosted by the fact that the overall defect potential is reduced. This reduction in defect potential, combined with the overall effort reduction, quantifies the intuitive adage that the cheapest defect to remove is an avoided defect.

While cost modeling tools have been used for budgeting and proposal purposes, they can be employed as a strategic tool to evaluate how changes in processes and methods will impact a software development organization. Cost modeling tools provide a tangible method for understanding how the use of new methods and tools can impact cost, schedule, and quality. In this case, it was demonstrated that investment in quality methods is justified. Additional benefits can be obtained when looking at required maintenance efforts. Having fewer defects means that less time is spent fixing problems, giving more time and resources to improving the system.

Table 3: *Defect Prediction Detail*

	Baseline	Introducing AUT	Difference	AUT + Experience	Difference
Potential Defects	738	756	2%	668	-9%
Defects Removed	654	675	3%	600	-8%
Delivered Defects	84	81	-4%	68	-19%
Defect Removal Efficiency	88.6%	89.3%		89.8%	
Hours/Defect Removed	36.52	37.41	2%	35.30	-3%

Summary

Adopting and enforcing best practices in software construction leads to better results at a lower cost. The practices outlined in this article are a good starting point for a quality improvement program in the construction phase of software development. These best practices can be implemented directly by a development organization, or incorporated into contractual requirements by an acquisition organization. Modeling tools can be used

to demonstrate the cost effectiveness of implementing best practices, and to help justify any initial cost to the development organization in instituting these practices.◆

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About the Authors

Rick Spiewak is a lead software systems engineer at The MITRE Corporation. He works at the Electronic Systems Center at Hanscom AFB as part of the 951st Electronic Systems Group, concentrating on Mission Planning. Spiewak's current focus is on the software quality improvement process and he spoke on this topic at the 2007 AF Information Technology Conference. He has been in the computer software industry for more than 37 years, and has bachelor's and master's degrees in electrical engineering from Cornell University. He also studied quality management at Philip Crosby Associates.

The MITRE Corporation
Command and Control Center
MS 1614E
202 Burlington RD
Bedford, MA 01730
Phone: (781) 266-9672
Fax: (781) 266-9748
E-mail: rspiewak@mitre.org

Karen McRitchie is vice president of development at Galorath Incorporated, and is responsible for design, development, and validation of current and new SEER cost estimation tools. For her longstanding contribution to commercial cost prediction tools, the International Society of Parametric Analysts honored her with its 2002 Parametrician of the Year award. McRitchie's most recent endeavors involve building parametric cost models for IT projects and ongoing support. She has a bachelor's degree in mathematics and system science from the University of California Los Angeles, and completed her master's work in mathematics at California State University, Northridge.

Galorath Incorporated
100 N Sepulveda BLVD
STE 1801
El Segundo, CA 90245
Phone: (310) 414-3222 ext. 622
Fax: (310) 414-3220
E-mail: karenm@galorath.com

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Data (mis)Management

While I wrote this column, I was at an altitude somewhere around 34,000 feet, flying from Albuquerque to Houston. I was working on a briefing I will be presenting, and started looking for a support file that had critical information (translation: I am looking for a Dilbert cartoon I used in a previous briefing). As I search and search unsuccessfully, I started thinking about the large amount of data that I carry with me, and the entirety of my "electronic life."

The 1980s: I was running the Control Program for Microcomputers (also known as CP/M), then the Commodore OS, then MS-DOS 2.11. My "life" consisted of no more than a dozen 160, then 180, and, later, 360KB 5 1/4-inch floppies. I probably carried 100-200 files with me when I changed jobs.

The 1990s: UNIX, SunOS, Windows 3.1, Macintosh OS Version 4.0, and Windows 95. My "electronic life" could be carried on several boxes of 1.4MB floppies, or maybe an eight millimeter tape, and eventually a few CDs. I actually found "Backup of Dave Cook's life" CDs from 1997, when I retired from the AF. Two CDs contained all that I felt worthy of keeping: 1,344 files, taking up about 1GB.

Now: Windows XP, and then Vista. I carry a 250GB portable hard drive when I travel, plus a few 8GB thumb drives with critical files. A complete backup of my "electronic life" (minus the music and videos) takes 12.5GB, and spans 11,218 files. Of course, that does not include 8GB that my more than 11,000 pictures takes up. Nor does it include the 7GB of music (1,334 songs) and 154GB of videos (27 movies that I will definitely watch ... someday!) If I converted all of this, it would take 286 CDs, or almost 130,000 of the 1.44MB floppies. Wow!

And, of course, it is becoming increasingly difficult to find a single file when I need something. I tried organizing my music into "Artist" folders. But then I ended up with "Misc," "Misc from my daughter," "Comedy," etc. It's the same with business files. I started out with Word documents and PowerPoint presentations ... then I realized that some should be grouped under a specific customer ... then some are sort of miscellaneous, based on a presentation or work from the past. I tried organizing them by date ("Files from 1998"), and then by job ("Stuff from STSC 1997-2003").

And now we have distributed data to worry about. I have an office machine, a home machine, a laptop that I travel with, and a spare laptop I keep in the living room (so I can surf and watch TV at the same time!). I have to occasionally worry about syncing my office and traveling machine. I often work on files at home. I try synchronizing everything, but occasionally, I have to panic and search frantically before a trip to find the latest copy of something. I DO have a process: I try to remember to send an updated file to myself (from home) in an e-mail, and I use various tools in trying to keep the data "in sync." I "officially" use my office machine as my "main" machine (and just clone a virtual volume to my laptop when I travel). The problem then revolves back to finding a single file on one computer. And that's where the current suite of tools occasionally fails me.

Nothing works perfectly. With Vista, I can just type in a phrase I want to locate ("SSTC 2006") and get lots of hits—none of which really helped me find that perfect Dilbert cartoon. Oh well, I have lots of Dilbert cartoons to choose from (173 in the "Dilbert" folder). Luckily for me, they all have helpful names ("Dilbert Cartoon June 1999"). Let's just face the facts: It's getting harder and harder to organize and arrange data so that you can easily find what you need.

Of course, I am sure you already know the BEST way to manage your data, right? If not, let me explain how to do it the RIGHT way so that you don't lose anything! Wait ... hold on ... I wrote it down ... I've just got to find the document on my computer ... I know it's here somewhere ...

—David A. Cook, Ph.D.
The AEgis Technologies Group, Inc.
<dcook@aegistg.com>

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